Uvular approximation as an articulatory vowel feature

Jonathan P. Evans
Institute of Linguistics, Academia Sinica (Taipei)
jonathan@sinica.edu.tw

Jackson T.-S. Sun
Institute of Linguistics, Academia Sinica (Taipei)
hstssun@gate.sinica.edu.tw

Chenhao Chiu
Department of Linguistics, University of British Columbia
chenhao@alumni.ubc.ca

Michelle Liou
Institute of Statistical Sciences, Academia Sinica (Taipei)
mliou@stat.sinica.edu.tw

This study explores the phenomenon of uvularization in the vowel systems of two Heishui County varieties of Qiang, a Sino-Tibetan language of Sichuan Province, China. Ultrasound imaging (one speaker) shows that uvularized vowels have two tongue gestures: a rearward gesture, followed by movement toward the place of articulation of the corresponding plain vowel. Time-aligned acoustic and articulatory data show how movement toward the uvula correlates with changes in the acoustic signal. Acoustic correlates of uvularization (taken from two speakers) are seen most consistently in raising of vowel F1, lowering of F2 and in raising of the difference F3-F2. Imaging data and the formant structure of [l] show that uvular approximation can begin during the initial consonant that precedes a uvularized vowel. Uvularization is reflected phonologically in the phonotactic properties of vowels, while vowel harmony aids in the identification of plain–uvularized vowel pairs. The data reported in this paper argue in favor of a revision of the catalog of secondary articulations recognized by the International Phonetic Alphabet, in order to include uvularization, which can be marked with the symbol [ʶ] in the case of approximation and [ᵡ] for secondary uvular frication.

1 Introduction

During uvular approximation, the tongue dorsum moves toward the uvula. Constriction of the styloglossus and other muscles shrinks the oropharyngeal isthmus (OPI), which is the open

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space above the tongue dorsum, drawing together the tongue body, soft palate, and uvula. This gesture plays a role not only in the articulation of uvular consonants, but also occurs during the production of those sounds in which a uvular gesture accompanies other articulations. Uvular secondary articulations, such as those found in the 'emphatic' consonants of some Arabic dialects, are often of a longer duration than the conditioning segment, e.g. for Jordanian Arabic, see Al-Tamimi & Heselwood (2011), Heselwood & Al-Tamimi (2011), Zawaydeh & de Jong (2011). Because uvularization accompanies a primary articulation at some location other than the uvula, the acoustic effect and the exact gesture of uvularization may be expected to differ from what occurs during a primarily uvular articulation.

Unequivocal evidence for phonemic vowel uvularization in other languages is elusive. Uvularized consonants are attested in Jordanian and Palestinian Arabic, St'át'imcets, Ju|'hoan, etc. In these languages, articulation of consonantal uvularization extends into neighboring vowels. Uvularized sounds in Ju|'hoan include the pulmonic plosives /tᵡ ʧᵡ dᵡ ʥᵡ ʤᵡ/ and the uvularized clicks /|ᵡ !ᵡ ǂᵡ ‖ᵡ ɡ|ᵡ ɡ!ᵡ ɡǂᵡ ɡ‖ᵡ/ (Miller-Ockhuizen 2003, Miller 2007). Ju|'hoan uvularization involves contact between the tongue and the uvular area, as evidenced by the 'uvular frication' of the release of the uvularized consonant. Uvularization in this language elevates F1 and increases the spectral slope, which Miller defines as the difference in amplitude between the first two harmonics (H1-H2). That is, for the part of the vowel that is affected by uvularization, the amplitude of lower frequencies is boosted relative to higher frequencies. On the other hand, glottalized and epiglottalized consonants show a decrease in spectral slope. All 'guttural' (laryngeal and pharyngeal) sounds in this language have a low harmonics-to-noise ratio (HNR), which indicates a noisy signal, such as a hoarse voice (Yumoto, Gould & Baer 1982). After release of the uvularized consonant, the acoustic effect of uvularization on the vowel tapers off, e.g. there is a 'gradual F1 transition, lasting over the first half of the vowel' (Miller-Ockhuizen 2003: 31). Miller-Ockhuizen's study only measured non-high vowels, because for high vowels, F1 was too close to f0 to investigate. Uvularization in Ju|'hoan is treated as a subset of pharyngealization (Miller-Ockhuizen 2003: 119). In this language, pharyngeal sounds, including those that are uvularized, are defined as having a constriction (not just an approximation) in the pharyngeal region, as is reflected in their noisy characteristics.

Shahin (2002) reports on acoustic properties of uvularization and pharyngealization in Palestinian Arabic and St'át'imcets. Based on the modeling of Stevens & House (1955), Shahin (2002: 37) summarizes the expected acoustic effect of pharyngealization as a medium to large rise in F1 (depending on the place of the primary constriction) and a medium drop in F2. The effect of uvularization is predicted to be a small rise in F1 and a medium drop in F2. The empirical studies she cites are in basic agreement with this prediction. Nevertheless, Shahin reminds the reader that one cannot reason backward from acoustic measurements to articulation, as 'a given set of formant frequencies will not in general correspond to a unique vocal tract configuration' (Shahin 2002: 39).

Articulatory investigations of Palestinian Arabic and St'át'imcets show that uvular articulations, also referred to as upper pharyngeal approximations, are accompanied by lower pharyngeal approximation as well. That is, retraction and raising of the tongue dorsum is complemented by retraction of the tongue root (Ghazeli 1977, Namdaran 2006). This trend could account for the controversy over whether Jordanian Arabic emphatics are uvularized or pharyngealized (Zawaydeh 1999, Al-Tamimi & Heselwood 2011, Heselwood & Al-Tamimi 2011, Zawaydeh & de Jong 2011). In addition, cinefluorographic images of Swedish and Greenlandic Inuit primary uvular consonants also show contraction in the upper pharyngeal region (Wood 2004). Furthermore, in both languages, tongue retraction for consonants causes tongue retraction on preceding and following vowels. Although Ju|'hoan uvularization is accompanied by a noisy release of uvular closure, Arabic and St'át'imcets tongue retraction appears to involve tongue approximation, rather than complete closure.

In addition to the above-mentioned linguistically distinctive uvularization, a similar phonetic effect is noted in certain speech disorders, in which the diacritic [ʶ] is used to

Table 1 Plain and uvularized vowels of Mawo and Yunlinsi Qiang.

Form	Mawo gloss	Yunlinsi gloss
/zi/	'be burdened with work or responsibilities'	'be burdened with work or responsibilities'
/ziʶ/	'ladle'	'ladle'
/zu/	'wait'	'wait'
/zuʶ/	'hail'	'hail'
/zə/	'field'	'field'
/zəʶ/	'seed'	'seed'
/za/	'easy'	'easy'
/zaʶ/	'scoop (VT)'	/dzaʶ/ 'tilted away from user (as head of hoe)'
/ze/	–	'beat up'

indicate uvular secondary articulation (Howard 2007: 24). The Voice Quality System (VoQS) of Ball, Esling & Dickson (1995) proposes the use of [Vʶ] for 'uvularized voice'. This system indicates voice quality that extends across segments, setting it apart with curly braces and voice quality indicators: ['ðɪs iz 'nɔ˞məɫ 'vɔɪs {Vʶ 'ðɪs iz 'juvjulə˞aizd 'vɔɪs Vʶ}]. Although it was not created for the purpose of specifying the articulation of individual segments, in this study we apply the symbol [ʶ] to mark uvularized segments.

The present study documents the existence of distinctive vowel uvularization in two varieties of Northwestern Qiang that are spoken in Heishui County, Sichuan, China. The argumentation proceeds as follows. Minimal sets reveal the phonemic status of each of the vowels (Table 1). Acoustic mapping shows that uvularized vowels are acoustically retracted (lower F2 and higher F3-F2) compared to their plain counterparts (Section 2). Articulatory studies based on ultrasound video imaging show that the tongue gesture in question is in fact directed toward the uvula (Section 3, supplementary materials online, along with the electronic version of this paper, at http://journals.cambridge.org/IPA). Ultrasound images that are time-aligned with spectrograms show the influence of tongue gestures on the acoustic signal.

Other languages of Southwest China have been described as having tense/lax vowels. In these cases (Bai, Yi, Jingpho, Wa, Hani, etc.), the description refers to glottal states on the breathy–modal–creaky continuum (Maddieson & Ladefoged 1985, Bao & Zhou 1990, Esling & Edmondson 2002, Edmondson & Esling 2006, Kuang 2011). However, unlike what is found in these languages, in Northwestern Qiang both uvularized and plain vowels have modal voicing.

Phonological evidence of uvularization in Qiang comes from phonotactic constraints, which show that vowels fall into two natural classes, only one of which (uvularized) can follow a uvular simple (not cluster) initial consonant, while only the other class (plain) follows velar simple initials. Both plain and uvularized vowels occur with labial and coronal initial consonants. Vowel harmony patterns yield a definitive pairing of corresponding plain and uvularized vowels (Section 4).

Although the discovery of uvularized vowels in these varieties has been documented (J. Sun & Evans 2013, Evans & J. Sun in press), the present work is the first to thoroughly explore the phonetic and phonological properties of vowel uvularization in Qiang, and the first to present articulatory imaging evidence that the feature in question does indeed involve a tongue gesture toward the uvula.

1.1 Overview of language and phenomenon

Qiang, also known as Rma from the autonym of its speakers, is a Sino-Tibetan language group spoken by more than 100,000 ethnic Qiangs and Tibetans in five counties of the Aba Tibetan-Qiang Autonomous Prefecture of Sichuan Province, China (ISO codes cng, qxs;

H. Sun 1981, Liu 1998). The present study investigates the Mawo and Luhua dialects of Northwestern Qiang, which is the principal indigenous language of Heishui County. The Mawo dialect is spoken in certain villages of Mawo Township; the analysis in this paper is based on the speech of Miao'erwo Hamlet in Zhaku Village. Across Heishui County, Mawo is considered a prestige dialect. The Luhua dialect is represented in this study by the Yunlinsi variety spoken in Yunlinsi Village of Hongyan Township, which lies just to the west of Mawo Township.

Mawo and Yunlinsi each have four distinctive plain vowels, which we transcribe /a ə i u/, and four uvularized vowels /aˁ əˁ iˁ uˁ/. In addition, Yunlinsi has /e/, which lacks a uvularized counterpart. Table 1 presents minimal sets exemplifying the distinctive vowels of these two dialects (there are no diphthongs in native monomorphemes); sound files are in the supplementary materials online.

2 Acoustic characteristics of uvularization

An acoustic study of the properties of uvularization was performed in order to quantify differences between the sound signals of plain and uvularized vowels.

2.1 Method

For the acoustic analysis, CV sequences containing the alveolar initials /t d s n l/ from both dialects were recorded in the phonetics laboratory at the Institute of Linguistics, Academia Sinica. The Mawo speaker was a 67-year-old male, while Yunlinsi words were pronounced by a 66-year-old male. All of the words used are native Qiang words, except for a few ancient borrowings from Tibetan, which were needed to fill out the matrix of contrasts (e.g. /staɹa/ 'ax'). The sequence of words was practiced, in order to reduce communication in Chinese during elicitation. Phonemic forms are given in Appendix A. After reviewing the words in question, each speaker said each word three times in isolation, as naturally as possible. The Yunlinsi subject has slight chronic hoarseness, which had a minor adverse affect on the sound quality of his recordings, although they showed clear formant structure. The digitally recorded files were transferred to a standard desktop computer, and were analyzed with Praat software (Boersma & Weenink 2013). The vowel was deemed to be that part of the waveform which contained obvious periodicity, and where the wave tracing was distinct, rather than noisy. The frequencies of the first three formants were obtained utilizing Praat's formant tracking, with the maximum frequency set to 5500 Hz. Within this range, the software was set to identify five or six formants, a number that was adjusted according to the vowel, as neither setting yielded adequate results for all vowels. For example, analysis of [u uˁ] required that Praat identify six formants below 5500 Hz, due to the low F1 and F2 of these vowels. Other settings were set to their standard values. Formant values were obtained at intervals of about 6 ms, according to the default settings of Praat. The first and last formant measurements were discarded to reduce unwanted edge effects.

Obvious formant miscalculations were fixed by interpolation. For each utterance, the median values of the first three vowel formants were obtained, and then the mean of the three medians was calculated, and taken as the summary statistic for the vowel of a given CV combination.

2.2 Results: Vowel formant values

Based on previous findings, we expected to find higher F1, lower F2, and higher F3-F2 for the uvularized vowels than for their plain counterparts. Hassan & Esling (2007) found that in vowels adjacent to Iraqi Arabic emphatics, F1 and F2 are closer together than in non-emphatic environments. This value was also explored in our data.

Summary values for each CV combination are given in Appendix A (Table A1). F1 vs. F2 plots for the two speakers are given in Figure 1.

Members of uvularized–plain vowel pairs can be perceptually distant, as evidenced by their visual separation in F1 × F2 vowel space. This fact lies in contradistinction to perceptual similarity of paired vowels in other systems, such as tense/lax vowels in English and Dutch.

Kent & Read (2002) claim that higher values of the difference F3-F2 correspond to increased tongue backness. Figure 2 plots F1 vs. F3-F2, and shows a clear increase in the latter dimension for uvularized vowels, with the exception of the Yunlinsi pair /i iʶ/. While this calculation is reminiscent of F2 prime (Kiefte, Nearey & Assmann 2013: 166–168), we make no claims about a role for F3-F2 in perception. The dimension F3-F2 also separates /ə iʶ/ more clearly than does F2 alone (Figure 1).

As suggested by the distribution within F1 × F2 acoustic space, some vowels are perceptually similar, e.g. Yunlinsi /ə iʶ əʶ/ and Mawo /ə iʶ/. In both dialects, /a aʶ/ sound similar to [æ ɑ], while the /u uʶ/ pair resemble [ʉ o]. Yunlinsi /e/ occurs as [je] after labials and dental/alveolars, and as [e] elsewhere. Yunlinsi forms containing /e/ are often cognate to /i/ in Mawo and /j-/ plus front vowel in other dialects: Yunlinsi /pe/, Mawo/Zhimulin /pi/, Luoduo /pjæ/, Qugu /pje/ 'pig'; Yunlinsi /le/, Mawo/Zhimulin /li/, Luoduo /ljæ/, Qugu /lje/ 'thick (board)'. This Yunlinsi vowel is treated as a monophthong for several phonological reasons. First, Yunlinsi has no contrast between [e je], unlike Qugu (/pe/ 'snow'; /pje/ 'pig'). Second, we do not propose /ie/, as it would be the only native diphthong in the language. Finally, we do not propose /jV/ because it is not clear what vowel would be chosen.

The choice of vowel symbols in our transcription reflects both phonetic and phonological considerations. Thus, although /u/ sounds rather like Swedish [ʉ], we chose the orthographically simpler transcription, due to a lack of contrast between [ʉ u]. Distinctive consonants and consonant clusters are presented in Appendix B (Tables B1–B3).

The first analysis performed on the data was a calculation of formant differences between uvularized and plain vowels. Table 2 gives the summary values (means of the median measurements) for both Yunlinsi and Mawo formants following alveolar initials.

The study performed a repeated measure ANOVA with two within-trial factors, namely formants (F1, F2, and F3-F2) and formant shifts within each of the uvularized and plain vowel pairs ([iʶ i], [əʶ ə], [aʶ a], and [uʶ u]), given that the shifts were nested within the formants. In the ANOVA, we additionally assumed that trials within each participant (18 trials each) were independent, which was deemed justified because the wordlists had been practiced, and the list of words was not long. In order to take into account possible differences between the two speakers, the two participants were taken as a covariate in the ANOVA; that is, all the main and interaction effects were statistically evaluated by holding the participant effect constant. Because the homogeneity-of-variance assumption was violated (Mauchly's test on sphericity was rejected for the main and interaction effects), we applied the Greenhouse–Geisser correction on degrees of freedom in the ANOVA for all within-trial comparisons. The ANOVA results suggested that both the formant effect ($F(1.164,39.56) = 438.793$, $p < .001$) and the shift effect ($F(2.162,73.521) = 59.994$, $p < .001$) were statistically significant. Furthermore, the interaction between formant and shift was also significant ($F(2.187,74.354) = 15.817$, $p < .001$), verifying that formants differ in their shift sizes and directions. The post-hoc evaluation of each mean shift between uvularized and plain vowels within each pair and for each formant is given in Table 3. The plots of mean shifts are given in Figure 3.

Table 3 shows that consistent and significant formant shifts are found in F2 (from –246 to –471 Hz) and in F3-F2 (from 142 to 560 Hz), both corresponding to acoustic backing of uvularized vowels. Positive shifts in F1 are consistent and significant for the non-schwa vowels. Thus, as in the pharyngealized vowels investigated in Hassan & Esling (2007), F2 and F1 are closer together (smaller value for F2-F1) for uvularized vowels than for their plain counterparts (see Table 2 above). To be more precise, F2-F1 for plain vowels averages more than 350 Hz higher than F2-F1 for corresponding uvularized vowels. Although this result was expected due to the established shifts in F1 and F2, we include it here to facilitate comparison

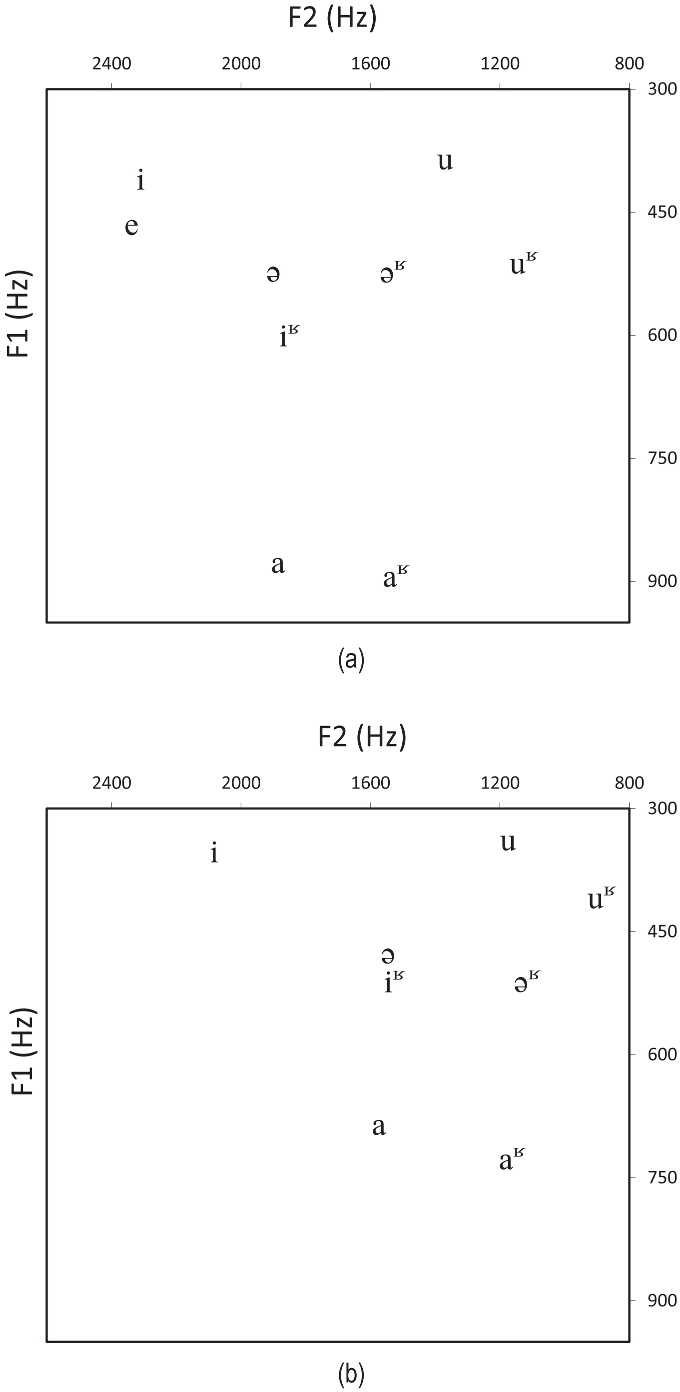


Figure 1 First two formants of (a) Yunlinsi and (b) Mawo vowels, following coronal initial consonants.

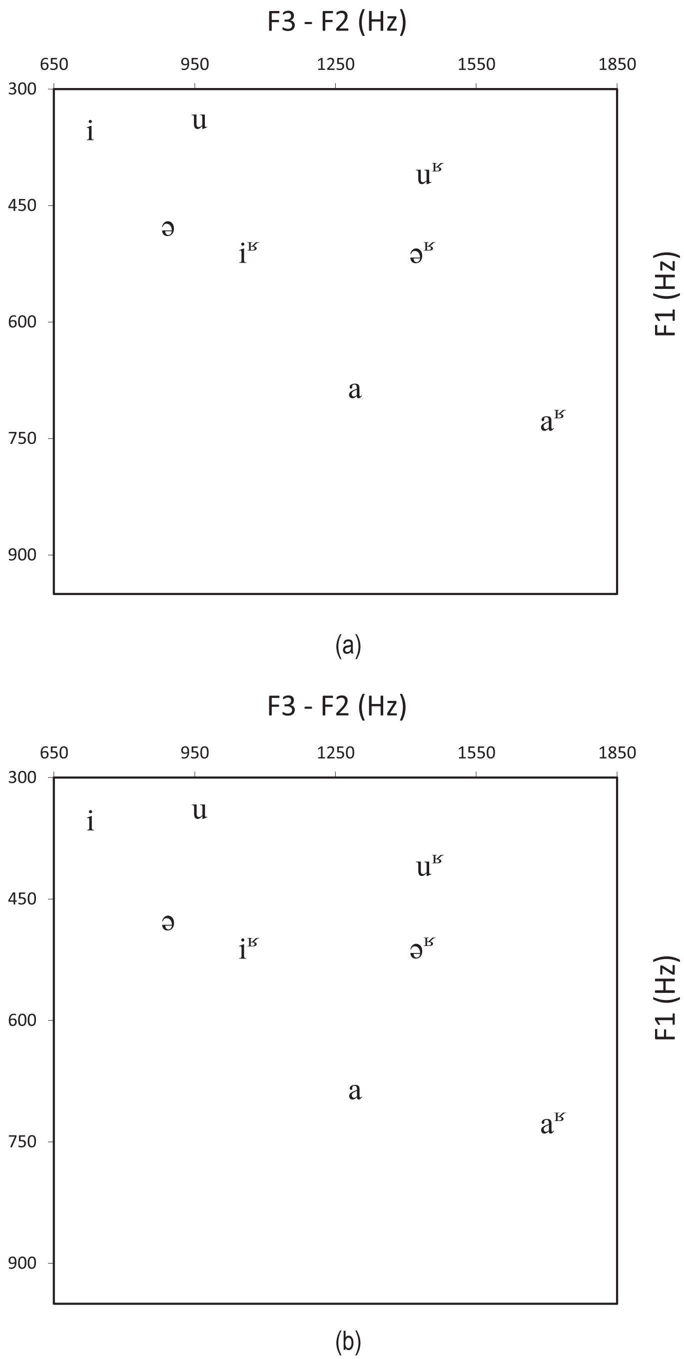


Figure 2 F1 vs. F3-F2 for (a) Yunlinsi and (b) Mawo vowels, following coronal initial consonants.

Table 2 Summary formant values (in Hz) for Yunlinsi and Mawo vowels.

Yunlinsi									
	i	iʶ	e	ə	əʶ	a	aʶ	u	uʶ
F1	408	599	463	520	521	875	892	383	510
F2	2310	1850	2339	1900	1530	1886	1521	1369	1126
F2-F1	1902	1251	1876	1380	1009	1011	629	986	616
F3	3367	2843	3211	2820	2898	2686	2840	2345	2856
F3-F2	1057	993	872	920	1368	800	1319	976	1730

Mawo								
	i	iʶ	ə	əʶ	a	aʶ	u	uʶ
F1	351	509	474	509	683	725	336	407
F2	2083	1526	1546	1116	1574	1162	1175	885
F2-F1	1732	1017	1072	607	891	437	839	478
F3	2811	2591	2439	2551	2865	2876	2135	2336
F3-F2	727	1065	893	1435	1291	1713	960	1451

Table 3 Results of post-hoc tests on the mean shifts (in Hz) for individual formants and uvularized–plain vowel pairs.

	[iʶ i]	[əʶ ə]	[aʶ a]	[uʶ u]
F1	159 (8) $t_{34} = 20.685$, $p < .001$	9 (10) $t_{34} = 0.915$, $p = .183$	88 (5) $t_{34} = 16.267$, $p < .001$	28 (10) $t_{34} = 2.726$, $p = .005$
F2	−471 (48) $t_{34} = -9.902$, $p < .001$	−391 (20) $t_{34} = -20.010$, $p < .001$	−246 (16) $t_{34} = -35.658$, $p < .001$	−358 (14) $t_{34} = -24.718$, $p < .001$
F3-F2	142 (38) $t_{34} = 3.717$, $p < .001$	431 (36) $t_{34} = 11.916$, $p < .001$	560 (36) $t_{34} = 15.590$, $p < .001$	427 (44) $t_{34} = 9.799$, $p < .001$

with other studies. F3 and F2-F1 were not tested in the ANOVA because F1, F2, and F3-F2 already take into account the relevant formants as explanatory variables.

2.3 Results: Formant values during initial /l/

Because the ultrasound video of the uvularized vowels shows a sequence of two tongue gestures (Section 3 below), we investigated whether there was a formant shift during the vowel articulation. The first and last third of the trimmed vowel duration was taken, and the medians of the first three formants of the two vowel portions were compared. The degree and directions of acoustic movement were similar for both uvularized and plain vowels, suggesting that there is no consistent tongue motion toward or away from the uvula during vowel articulation, at least in careful speech for these two speakers. The lack of prominent formant shift during vowel articulation suggested that acoustic correlates of uvularization might be found during articulation of the initial consonant. To investigate this possibility, formant values of the voiced lateral initial consonant [l] were sampled before each of the vowels, using the technique described earlier (Figure 4). Compared to vowel space (Figure 1 above), [l] shows a lower top-end range for F2, and, in Mawo, a very small F1 range. Although

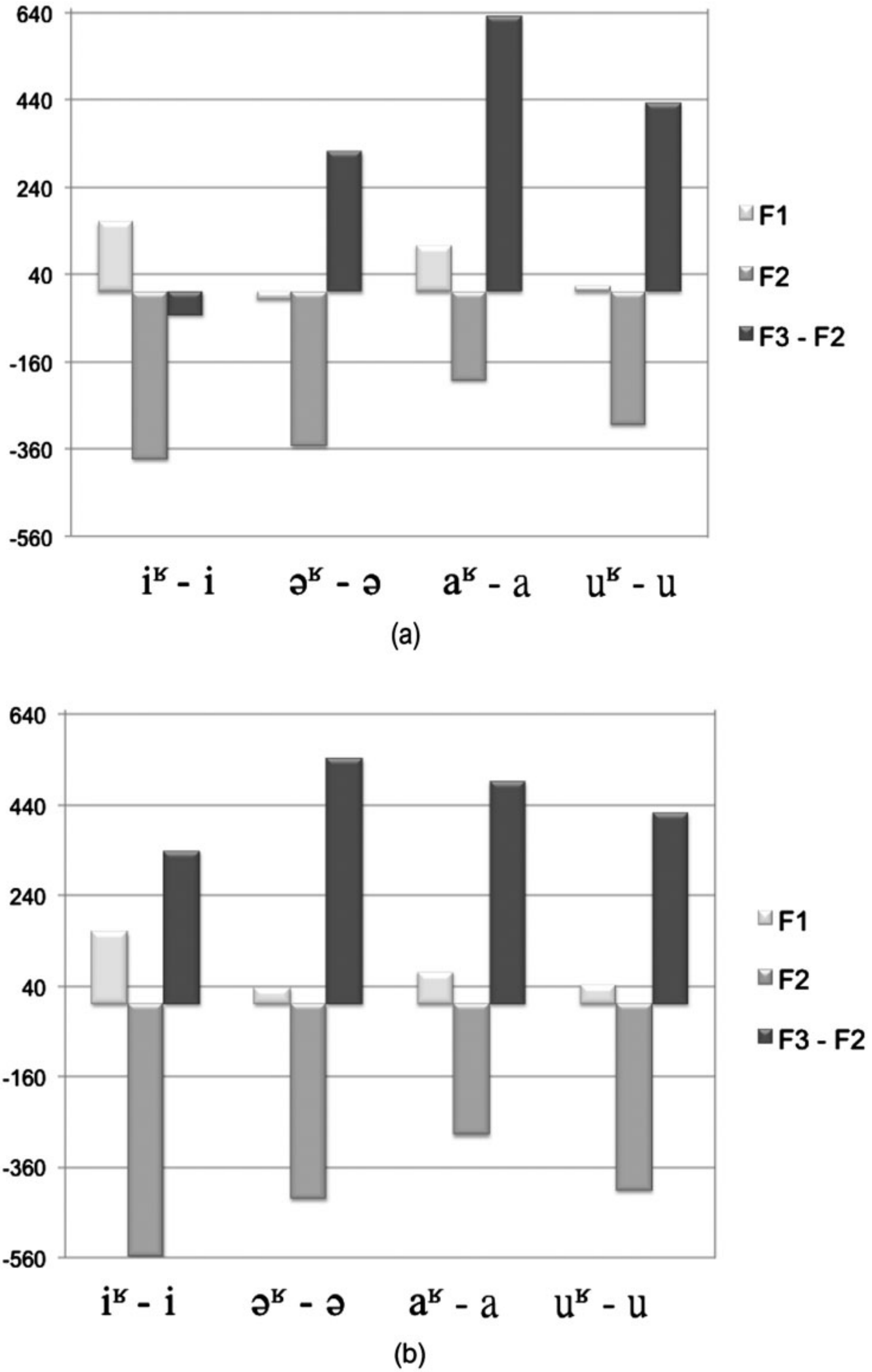
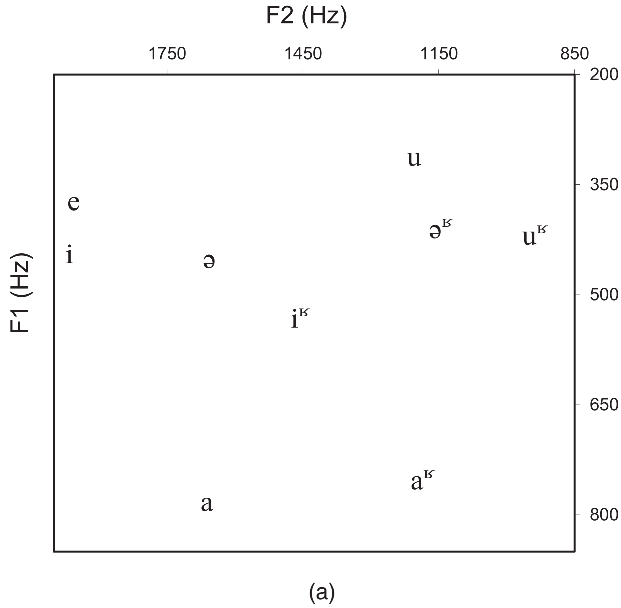


Figure 3 The mean shifts in Hz of (a) the Yunlinsi speaker and (b) the Mawo speaker for each formant and each uvularized–plain vowel pair.



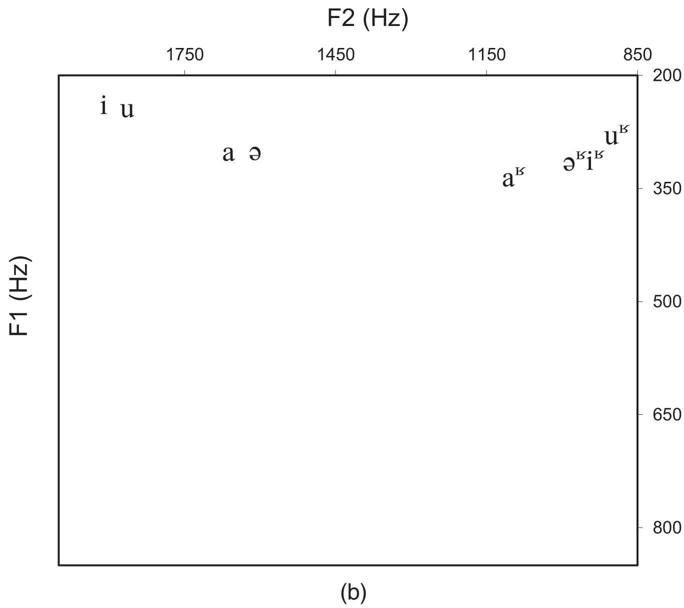


Figure 4 First two formants during initial [l] in (a) Yunlinsi and (b) Mawo.

both speakers show acoustic retraction (lower F2) for uvularized vowels relative to their plain counterparts, the Mawo speaker shows a more consistent overall acoustic retraction effect. The dimension F2 was chosen over F3-F2, due to better acoustic separation for vowels following [l].

Tables 4 and 5 show F1, F2, F3, and F3-F2 for [l] preceding each of the vowels, along with the formant differences for Yunlinsi and Mawo respectively. Because there are only three /l/-initial samples for each vowel, formal statistical tests were not applied.

Table 4 Yunlinsi formant values.

(a) Summary formant values (in Hz) for [l] preceding the given vowels

	i	iʶ	e	ə	əʶ	a	aʶ	u	uʶ
F1	443	530	370	449	408	780	751	310	417
F2	1966	1456	1956	1657	1145	1662	1186	1205	938
F2-F1	1523	926	1586	1208	737	882	435	895	521
F3	2752	2108	2738	2366	2239	2387	2072	1921	2353
F3-F2	786	652	782	709	1094	725	886	716	1415

(b) Formant value differences (in Hz) for [l] preceding uvularized–plain vowel pairs

	iʶ i	əʶ ə	aʶ a	uʶ u
F1	88	−41	−29	107
F2	−509	−512	−476	−267
F2-F1	−597	−471	−447	−374
F3	−644	−127	−315	432
F3-F2	−134	385	161	699

Table 5 Mawo formant values.

(a) Summary formant values (in Hz) for /l/ preceding the given vowels

	i	iʶ	ə	əʶ	a	aʶ	u	uʶ
F1	237	311	298	312	299	333	241	277
F2	1911	934	1610	975	1663	1096	1864	891
F2-F1	1674	623	1312	663	1364	763	1623	614
F3	2895	2262	2605	2454	2700	2953	2500	2506
F3-F2	985	1327	995	1479	1037	1857	636	1615

(b) Formant value differences (in Hz) for [l] preceding uvularized–plain vowel pairs

	iʶ i	əʶ ə	aʶ a	uʶ u
F1	74	14	34	36
F2	−976	−635	−567	−973
F2-F1	−1051	−649	−601	−1009
F3	−634	−151	253	6
F3-F2	343	484	819	979

For the Yunlinsi speaker, lowering of F2 and shrinking of the difference F2-F1 before a uvularized vowel are the only consistent shifts among the formants of [l]. In this context, F2 is lowered by between –270 and –510 Hz, a shift that is slightly larger than the F2 shift observed on the vowels themselves (see Table 4). An acoustic retraction of this magnitude is consistent with ultrasound imaging that shows that the uvular gesture starts before the vowel is articulated. The differences in the F1 measurements of [l] before high vowels also reflect the shift in F1 frequencies for the high vowels themselves (see Tables 2, 3), further corroborating the hypothesis of anticipatory uvularization.

Although the Mawo speaker's F1 range is much smaller than the Yunlinsi speaker's (Figure 4), consistent shifts were observed in F1, F2, and F3-F2 (Table 5).

Comparing Table 5b with Table 2, it may be noted that the shift in Mawo F2 is larger during the [l] than during the subsequent vowel. This leads to a larger shift in F2-F1 as well, a value which is smaller for uvularized vowels, as expected. The shift in F3-F2 during [l] ranges from about the same size as during the vowel for [iʶ i], [əʶ ə], to much larger for [l] during [aʶ a], [uʶ u]. The lowering of F2 and the raising of F3-F2 are consistent with an anticipatory retraction of the tongue during [l] before uvularized vowels. The large magnitude of F2 differences during initial [l], relative to these differences during vowel articulation, is consistent with the ultrasound images that show formation of the uvularization gesture during articulation of the initial consonant for the Yunlinsi speaker (Section 3).

3 Articulatory characteristics of uvularization

Ultrasound imaging has emerged as a safe noninvasive way to image tongue movements in linguistic research. In this study, ultrasound videography, time-aligned with the acoustic channel, shows movement toward the uvula for uvularized vowels (ultrasound videos are included in the supplementary materials).

3.1 Method

3.1.1 Participant

The male native speaker of Yunlinsi Qiang mentioned above was recruited for the ultrasound session. The consultant had normal speech and hearing, albeit with slight hoarseness. The collection session was accomplished in the Institute of Linguistics, Academia Sinica. Human research ethics approval for this study was obtained before ultrasound data collection commenced (#AS-IRB02–101031), and the speaker willingly consented to participate in the data collection.

3.1.2 Apparatus

An Aloka SSD-5000 ultrasound machine was used to collect tongue images with a UST-9118 endo-vaginal 180° electronic curved array probe under the consultant's chin. The transducer was stabilized on a fixed arm in order to minimize transducer movement. The ultrasound machine was connected to a Canopus ADVC-110 advanced digital video recorder. The images of the tongue surface were collected using simultaneous B-mode ultrasound aligned with the acoustic signal. The images of the midsagittal plane were captured at 30 frames per second. A high fidelity microphone was mounted on a microphone stand and placed in front of the consultant's mouth at a distance of approximately 30 cm. The microphone was plugged into a USB pre-amplifier and output to the Canopus card so that the ultrasound images and the audio are time-aligned. Speech output was sampled at 44.1 kHz.

3.1.3 Materials

Three Yunlinsi wordlists were created with target words filling out a matrix of CV combinations. The consonant for the target word was one of [b/p s l], matched with either a plain vowel (hereafter CV) or a uvularized vowel (hereafter CVR). All plain–uvularized pairs were investigated. The vowels under investigation include [i iʶ ə əʶ a aʶ u uʶ]; forms uttered are found in Appendix A (Tables A1 and A2).

3.1.4 Procedure

The consultant was asked to sit still with no head movements throughout the recording. The first author watched the angle and the position of the transducer during the recording session. Prior to data collection, the consultant produced a few tokens of [qaʶ] 'I', allowing the third author to locate the uvular contact with a fixed line on the ultrasound image. The line is preserved in Figure 5. Re-calibration was conducted before recording each wordlist.

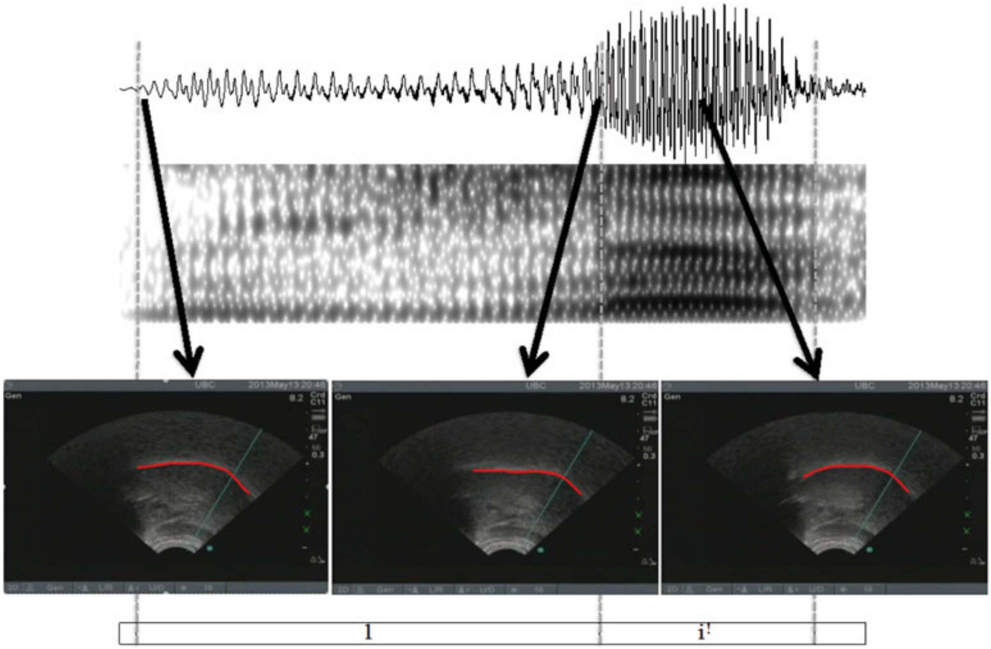


Figure 5 (colour online) Ultrasound images grabbed at three different instances in the example of [liʶ]: the onset of the consonant (the leftmost), the onset of the vowel (the center), and the midpoint of the vowel (the rightmost). A green cursor line slanting upward toward the right identifies the direction of the uvular place of articulation. Tongue surface was automatically indicated by EdgeTrak (red curves). The tongue tip is on the left side of the image and the tongue root is on the right.

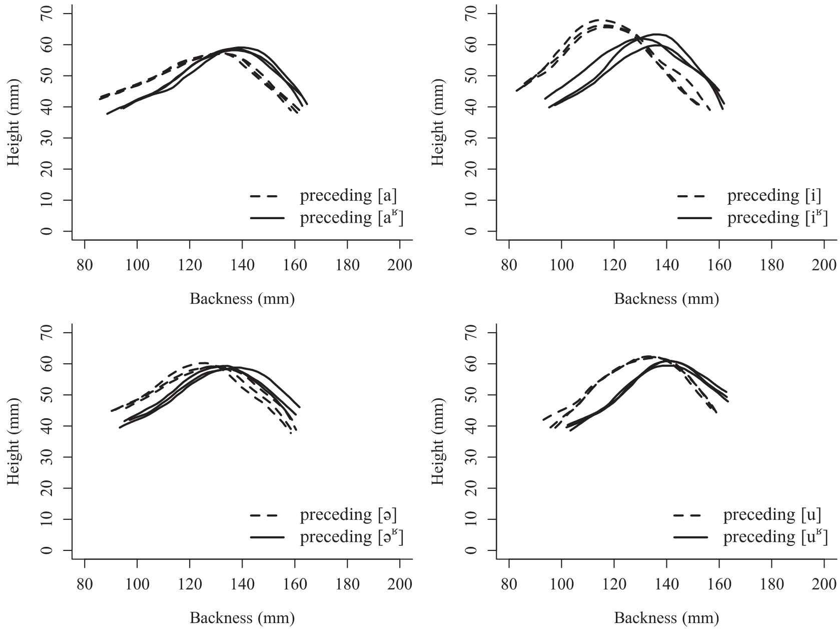
The second author interacted with the consultant during the data collection. The experimenter pronounced a target word in Mandarin Chinese and the consultant was probed to give the Qiang equivalent. Each target word was repeated three times by the consultant.

The ultrasound images were recorded as video clips by the third author. Simultaneously, participants' acoustic production was recorded concurrently with ultrasound images. Syllable boundaries and segments of the consonants and vowels were first labeled using Praat, and then loaded and aligned with videos using ELAN. Based on inspection of the audio and video files, images at three time points were grabbed from the videos: (i) the onset of the initial consonant, (ii) the onset of the vowel, and (iii) the center of the vowel (see Figure 5).

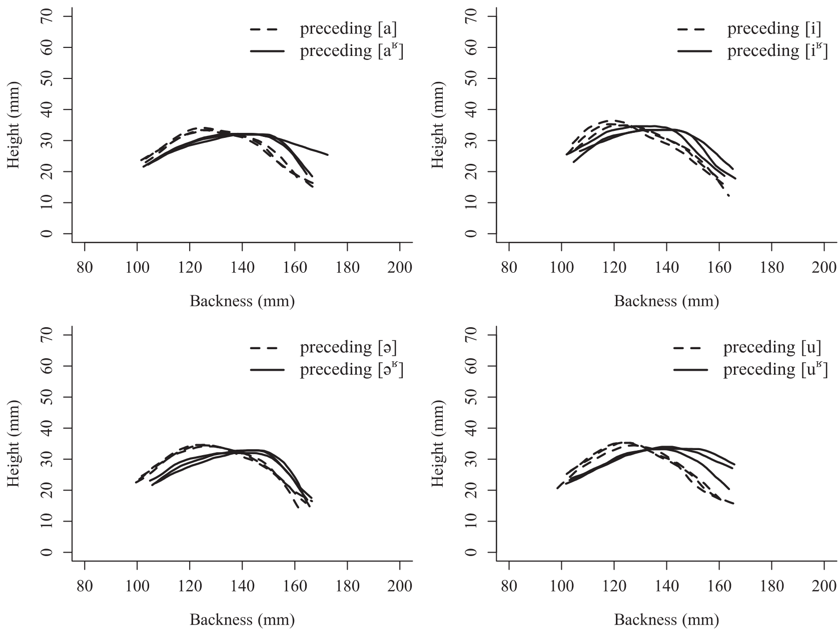
Grabbed images were imported to EdgeTrak (Li, Kambhamettu & Stone 2005) for tongue surface tracing. The coordinates of each image were spatially aligned. The tongue surface was automatically traced with the optimal fit (red curves in Figure 5). The coordinates of the tracing were logged for future figures.

3.2 Results

Figure 6 plots the tongue surface tracing across the three word lists. Figures 6a, b, and c show the tongue position at the onset of [b], [s], and [l], respectively. As shown in the figure, the tongue posture is more retracted for the consonants preceding a uvularized vowel (i.e. solid lines in Figure 6) than when preceding a plain vowel (i.e. dashed lines in Figure 6). At the onset of [b], since no specific tongue posture is required, the tongue is anticipatorily prepared for the posture of the following vowel. In Figure 6a, it is observed that the tongue posture at the onset of CV corresponds to the vowel position of the following vowel (e.g. high-front position for [b] in [bi]). In a CVR context, the tongue height is relatively unchanged, but

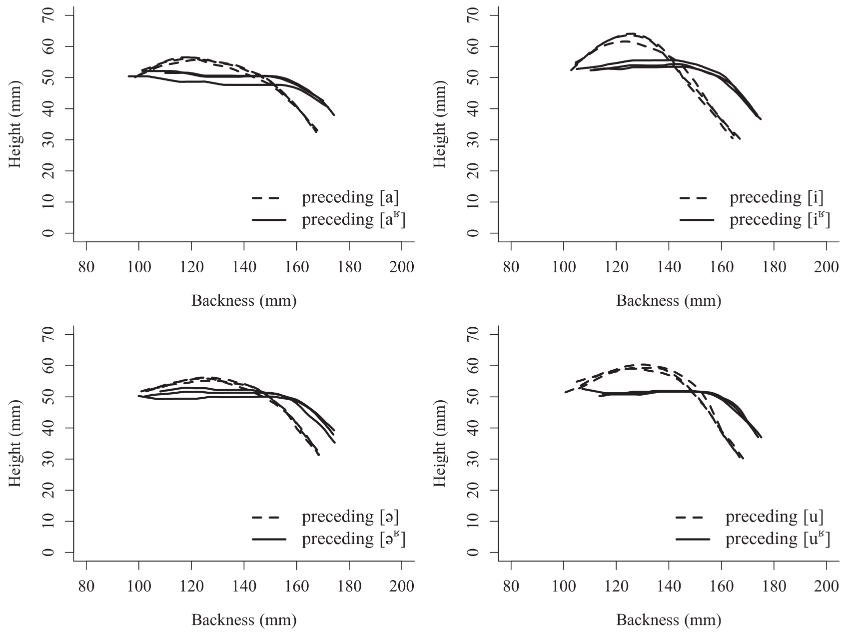


(a) The tracing of the tongue surface at the onset of [b]



(b) The tracing of the tongue surface at the onset of [s]

Figure 6 The tracing of the tongue surface at the onset of the consonant. Tongue postures of consonants preceding a plain vowel (CV context) are dashed lines whereas tongue postures of consonants preceding a uvularized vowel (CVR context) are outlined as solid lines. The x-axis marks the distance (in millimeters) from the tongue tip to the tongue root (i.e. the backness of the tongue), with the tongue tip on the left. The y-axis labels the height of the tongue in millimeters.



(c) The tracing of the tongue surface at the onset of [l]

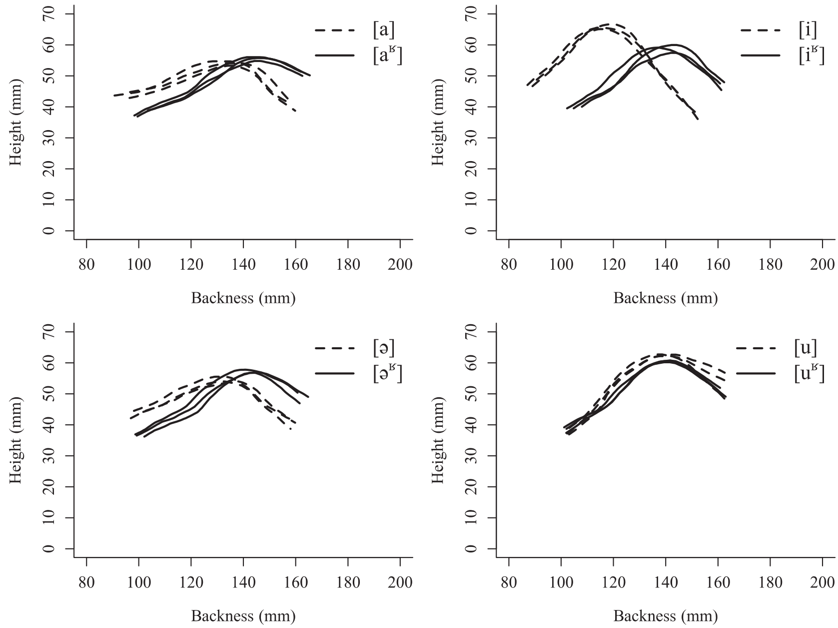
Figure 6 Continued.

the tongue is overall retracted. Similarly, anticipatory articulation was observed for [s] and [l] tokens in CV contexts (Figure 6b, c). However, the tongue body at the onset of [l] was flattened when it is followed by a uvularized vowel (i.e. CVR context). When a uvularized vowel is anticipated, the tongue body is retracted and raised towards the uvular area even before the onset of the vowel. Meanwhile, in order to maintain the lateral constriction for the consonant [l], the tongue tip was held in contact with the alveolar ridge, consequently the upper tongue surface appears flat.

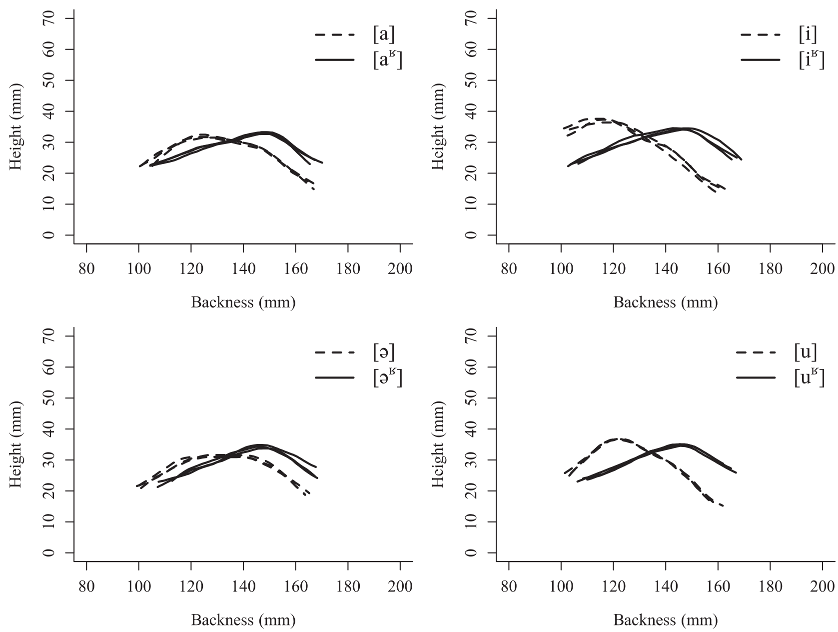
The tongue postures at the onset of the vowel were also traced using EdgeTrak. As predicted, the tongue in CVR contexts is retracted and raised towards the uvular area (see Figure 7). Such retraction movements are observed at the onset of the vowel. The retraction is a high and back movement of the tongue when it is preceded by [b] (Figure 7a) or [s] (Figure 7b) whereas the retraction only involves a backward movement of the tongue when it is preceded by lateral consonant [l] (Figure 7c).

These motions contrast with the directions of tongue movement seen in retracted tongue root (RTR), which is a constriction of the lower pharynx. Gick (2002) shows that in Kinande and Nuu-chah-nulth, RTR vowels have a tongue body that is lower or flatter than the corresponding non-RTR vowels. The highest point of the tongue has about the same degree of backness in both RTR and non RTR vowels. In addition, in RTR vowels, the back of the tongue indicates retraction via a flatter slope upward from the back of the tongue toward the highest place of the tongue body. However, in uvularized Qiang vowels, there is a tendency for the highest point of the vowel to shift toward the back of the mouth, relative to the highest point of plain vowels. In Figure 7 this tendency is most clear following [s b]. Given the flatter shape of uvularized vowels following [l], it is possible that articulation of uvularized vowels in this context does involve some pharyngealization.

It is noted that the tongue is not retracted further for [puʶ] than for [bu] (Figure 7a). The exact reasons for this await further experimentation. However, we note that articulation of

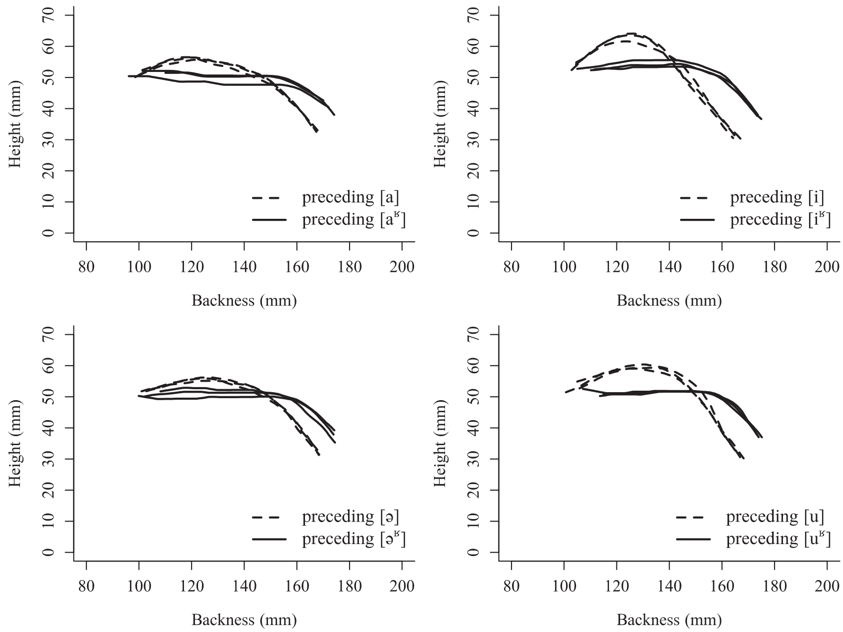


(a) The tracing of the tongue surface at the onset of the vowel following [b]



(b) The tracing of the tongue surface at the onset of the vowel following [s]

Figure 7 The tracing of the tongue surface at the onset of the vowel. The tongue postures of plain vowels are dashed lines (CV context) whereas the tongue postures of uvularized vowels (CVR context) are outlined as solid lines. The x-axis ticks the distance (in millimeters) from the tongue tip to the tongue root (i.e. the backness of the tongue), with the tongue tip on the left. The y-axis labels the height of the tongue in millimeters.



(c) The tracing of the tongue surface at the onset of [l]

Figure 7 Continued.

bilabial stops involves total closure of the mouth, which may allow less tolerance for tongue dorsum positioning than during articulations with less closure (e.g. coronal). If that is the case, then during preparation for articulating [u] during bilabial closure, the tongue dorsum might press against the velum area, limiting space for further retraction or raising under conditions of uvularization.

Thus, when following labials, the tongue posture at the onset of the vowel is therefore expected to be the posture of the vowel at its maximum constriction. When the vowel [u] is raised and retracted toward the back of the mouth, there remains limited space for the tongue to move any higher or further back. An alternative retraction would have been a downward retraction (i.e. pharyngealization). When the target word was probed, the production of the vowel shows a high, back retraction, rather than a low, back retraction. This therefore disfavors the proposal of pharyngealization as the main secondary articulation. Similar robust high-back retractions were also observed for uvularized vowels following alveolar fricative [s] (Figure 7b).

Figure 7c shows the tongue posture at the onset of the vowel following the lateral [l]. Similarly to the tongue posture at the onset of the consonant, the tongue remains in a flat posture in CVR contexts. The tongue position is further back than its counterpart in CV contexts (see solid lines in Figure 7c). The fact that there was no obvious upward movement for the uvularized vowel may be due to a coarticulatory effect between the preceding consonant [l] and the uvularized vowel. Comparing Figures 6c and 7c, it has been observed that the tongue postures at the onset of the consonant and the onset of the uvularized vowel were comparable, suggesting that the lateral constriction of [l] may dominate the overall tongue posture and forces the tongue to maintain a certain height. When a retraction occurs, the tongue is moved backward and only limited tongue raising was observed.

Table 6 Phonotactics of plain and uvularized vowels (Mawo).

	i	iʶ	u	uʶ	ə	əʶ	a	aʶ
k-	/ki/ 'house'	*	/ku/ 'turnip'	*	/kə/ 'go'	*	/kaχuʶ/ 'koklass pheasant'	*
q-	*	/qiʶ/ 'win'	*	/quʶ/ 'afraid'	*	/qəʶ-/ 'head'	*	/qaʶ/ 'I'

Tracing of the tongue surface grabbed at the midpoint of the vowel is illustrated in Appendix C (Figure C1). This figure shows that the upward retraction that marks uvularization continues from the onset to the midpoint of the vowel; thus the tongue surface images in Figures 7 and C1 are similar.

For all images of [a aʶ], the tongue appears to be at a fairly high position, as opposed to the traditionally defined low position. There are two probable reasons for this. The first is that we did not control for opening of the jaw, such that at a constant distance from the probe, there could be a range of distances between the tongue surface and the roof of the mouth. Expansion of the oral cavity to produce the acoustic properties of [a aʶ] was complemented by jaw lowering and (possibly) the raising of the maxilla. Thus, while we believe that the tongue shape and front-back positioning are accurate, the surface of the tongue during [a aʶ] was probably lower than it appears to be in the images.

Second, obtaining clear sagittal images requires pressing the ultrasound transducer firmly into the soft tissue behind the chin. It may be that this position pressed firmly on the tongue and consequently limited the lowering of the tongue body during the production of [a aʶ].

4 Phonological properties of plain and uvularized vowels

Vowel uvularization plays an important role in Northwestern Qiang phonology. In particular, uvularized vowels are typically restricted in their occurrence after velar consonants, while plain vowels tend not to occur after uvular consonants. The two sets of vowels contrast in other environments, as seen in Table 1 above. Vowels distinguished by the feature [±uvularized] can be acoustically distant from one another; vowel harmony patterns aid in the identification of plain–uvularized pairs. Finally, the phonological properties of uvularization help to demonstrate that it is primarily a property of vowels, rather than of consonants or syllables. Phonotactics, vowel harmony, and the suprasegmental status of uvularization are covered in the present discussion.

4.1 Phonotactics of uvularized vs. plain vowels

Mawo consonant–vowel phonotactics demonstrate the division of vowels into two equal classes. The plain class of vowels does not occur with uvular initials, while the uvularized class does not occur with velar initials (Table 6).

The observation holds for all velar/uvular simple (non-cluster) initials in Mawo. One possible interpretation of the data in Table 6 is that the velar and uvular consonants are not phonemically distinct. However, velar and uvular initials do contrast in cluster onsets before plain vowels, although (near-)minimal pairs like the following are rare:

Table 7 Distribution of plain and uvularized vowels in Mawo.

Vowel type	V	Vʁ
Labial	+	+
Dental	+	+
Alveopalatal	+	+
Retroflexed	+	+
Palatal	+	-
(Labial-)Velar	+	-
Uvular	-	+
Glottal	+	+

(1) *Mawo velar and uvular initial consonant contrasts*

/ɣli/	‘be level’	/xli/	‘reheat’
/ʁliʃə/	‘illegitimate child’	/χli/	‘fall out (through opening)’

For a few clusters, both plain and uvularized vowels can follow a uvular initial, further verifying the phonemic status of uvular consonants and the plain–uvularized vowel distinction:

(2) *Mawo plain and uvularized vowel contrasts after uvular initial*

/χli/	‘fall through opening’	/ʁdʐ̩u-dʒu/	‘underground water hole’
/χliʁ/	‘shady side of mountain’	/ʁdʐ̩uʁ/	‘Jew’s harp’

The overall distribution of plain versus uvularized vowels in Mawo is as presented in Table 7 (Yunlinsi monosyllabic alveopalatal–uvularized combinations are rare).

Yunlinsi CV patterns are very similar to those in Table 7, differing only in having weaker constraints on velar and uvular initials. Although Yunlinsi distribution patterns are more nuanced than those of Mawo, they still suggest a distinguishing feature of uvularization. The phonotactic properties of initial velar and uvular consonants and clusters are summarized in Tables 8, 9, and 10. Yunlinsi’s ninth vowel, /e/, is not phonotactically restricted, being the only vowel that occurs with each velar and uvular simple initial. For the purpose of clarity, /e/ is left out of these three tables.

Table 8 shows that simple (non-cluster) uvular initial consonants occur freely with uvularized vowels, but only occur with plain vowels when the content is specialized (onomatopoeia or a grammatical morpheme). No one vowel occurs with all of the velar and uvular initials, with the strongest restriction on /iʁ əʁ/, which only occur with uvular initials. Velar initial consonant /x-/ only occurs with plain vowels, although /k- k^h- g-/ are less restricted.

The phonotactics between cluster initials and vowels is slightly more complex. For those syllables with an initial consonant cluster in which C1 is velar or uvular, and C2 is not an oral stop or affricate, the nucleus agrees in uvularity with C1. Table 9 shows that vowels following /gz- ʁz-/ agree in uvularity with the initial consonant, while simple /z-/ co-occurs with both plain and uvularized vowels.

Table 8 Phonotactics of plain velar and uvular initials in Yunlinsi.

	/i/	/iʶ/	/ə/	/əʶ/	/a/	/aʶ/	/u/	/uʶ/
k-	/ki/ 'house'	*	/kə/ 'go'	*	/ka/ 'pulse'	/kaʶχuʶ/ 'koklass pheasant'	/ku/' 'turnip	*
kʰ-	/kʰi/ 'want'	*	/kʰə-laʶ/ 'crippled person'	*	/kʰa/ 'lean sth against sth else'	/kʰaʶ/ 'square (of cloth)'	/kʰu/ 'pick (grain)'	/kʰuʶsɑ/ 'room of a house'
g-	/gi/ 'road'	*	/gə/ 'flat-bread pan'	*	/gaga/ 'thread divider'	*	/gu/ 'back basket'	*
x-	/xi/ 'red'	*	/xə/ 'exert effort'	*	/xa ~ kʰa/ 'steep'	*	/xu/ 'able to eat more'	*
q-	*	*	*	/qəʶpaʶtʂə/ 'head'	*	/qaʶ/ 'I'	*	/quʶ/ 'fear'
qʰ-	*	*	*	/qʰəʶ qʰəʶ/ 'loosen'	*	/qʰaʶ/ 'bitter'	*	/qʰuʶ/ 'loss'
ʁ-	*	/ʁe-nu/ 'wasp'	*	/ʁɹəʶ/ 'Han'	*	/ʁaʶ/ 'be real'	*	/ʁuʶ/ 'willing'
χ-	*	*	*	/χəʶ/ 'full of food'	*	/χaʶ/ 'yellow'	*	/χuʶ/ 'tiger'

Table 9 Phonotactics of Yunlinsi /gz- ʁz- z-/.

	/i/	/iʶ/	/ə/	/əʶ/	/a/	/aʶ/	/u/	/uʶ/
gz-	/gzi/ 'fly (v)'	*	/gzə/ 'set out'	*	[gza] /gzə-a/ 'I set out'	*	/gzu kə/ 'marry into husband's family'	*
ʁz-	*	/ʁziʶ/ 'frugal'	*	/ʁzəʶ/ 'fish'	*	/ʁzaʶ/ 'collapse (of wall)'	*	/ʁzuʶ/ 'chisel'
z-	/zi/ 'be burdened with work or responsibilities'	/ziʶ/ 'ladle'	/zə/ 'field'	/zəʶ/ 'leak'	/za/ 'easy'	*	/zu/ 'wait'	/zuʶ/ 'hail'

For syllables with an initial cluster in which C1 is uvular and C2 is an oral stop or affricate, both plain and uvularized vowels can occur in the nucleus (Table 10). That is, these clusters occur with a subset of the vowels that occur with only C2.

The phonotactic properties of vowels with velar and uvular consonant initials reveal that the vowels form two sets: one set (uvularized vowels) is more compatible with uvular onsets than with velar onsets, while the opposite is true for the other set (plain vowels). Competing analyses for this distinguishing feature (e.g. velarization, pharyngealization)

Table 10 Distribution of Yunlinsi /χtʂ- χtʃ- χp-/ versus simple /tʂ- tʃ- p-/.

	/i/	/iʶ/	/ə/	/əʶ/	/a/	/aʶ/	/u/	/uʶ/
/χtʂ-/	/χtʂe ho/ 'well-mannered'	*	/χtʂə/ 'six'	*	*	/χtʂaʶ/ 'small'	*	/χtʂuʶ:/ 'prayer flag placed outside of door'
/tʂ-/	/tʂi/ 'ideophone describing heavy blowing sound'	*	/tʂə/ 'mule'	*	/ˈtsa tʂa/ 'this place'	/tʂaʶ/ 'filter (v)'	/tʂu/ 'gawk'	[tʂɹuʶ:] /tʂə-ɹuʶ/ 'herd of horses and mules'
/χtʃ-/	/χtʃi/ 'love'	*	/χtʃə/ 'neck'	*	/χtʃa:/ 'coral jewelry'	*	/χtʃu/ 'small bag'	*
/tʃ-/	/tʃi/ 'male person'	*	/tʃə/ 'butcher (v)'	*	/tʃa/ 'sour'	*	/tʃu/ 'come (PERF)'	/tʃuʶ:tʃu/ 'kiss'
/χp-/	/tʃaχpi/ 'rob'	*	*	χpəʶ /χpəʶnə/ 'monk'	*	/χpaʶ χpəʶ/ 'example'	/χpu:/ 'very'	*
/p-/	/pi/ 'become'	/piʶ/ 'thick (rope)'	/pələ/ 'cemetery'	/pəʶ/ 'tares'	/pa/ 'bloom'	/paʶ/ 'cool off, turn cold'	/pu/ 'buy'	/puʶ/ 'five liter dry measure'

would be challenged to account for the occurrence of one set of vowels with uvular initials and the other set with velar initials.

4.2 Vowel harmony

Evidence from vowel harmony reveals that uvularized vowels are united by a feature that can migrate across syllable boundaries, assimilating vowels in neighboring syllables. Vowel harmony also provides the evidence required to associate plain and uvularized vowels in pairs. This step is a necessary part of the analysis, because members of plain–uvularized vowel pairs can be acoustically divergent, as shown in Figures 1 and 2 above. Likewise, vowels that are acoustically similar, such as /ə iʶ/, often belong to different plain–uvularized pairs. In these two varieties, usually uvularization harmonizes leftward, as seen in Table 11.

In this study we have analyzed uvularization in Northwestern Qiang as a vowel property. Two alternate proposals are that uvularization is a consonantal feature, like most analyses of Arabic emphatics, or that it is specified at the syllabic or morphemic level, like analyses of tone in many languages. There are two main reasons why we did not posit uvularization as a consonantal feature. First, this analysis would nearly double the number of distinctive consonants in the inventory. For example, in the case of Yunlinsi, 63 consonant phonemes would be required to account for the contrasts, instead of the current 35. Furthermore, a

Table 11 Yunlinsi plain–uvularized vowel pairs in harmony.

Vowel pair	Plain vowel	Gloss	Uvularized vowel	Gloss
/i iʶ/	/ksi/	'three'	/ksiʶ-suʶ/	'thirty'
/ə əʶ/	/gʒə/	'four'	/gʒəʶ-suʶ/	'forty'
/a aʶ/	/kʰɹa/	'eight'	/kʰɹaʶ-suʶ/	'eighty'
/u uʶ/	/tu-lu/	'come up'	/tuʶ-qsuʶ/	'jump up'

system of consonantal harmony would need to be proposed, in which uvularization would be the only feature that harmonized. This consonantal harmony system would function alongside a vowel harmony system which spreads height, roundness, etc. onto prefix vowels.

We do not propose uvularity as a syllable- or morpheme-based feature, because such an analysis would not account for the fact that uvularized vowels do in some cases occur with velar initials, e.g. Yunlinsi /ka/ 'pulse', /kaʶχo/ 'koklass pheasant'. Likewise, under vowel harmony conditions, vowels can uvularize, but velar consonants do not become uvular, e.g. /ksi/ 'three', [ksiʶ-suʶ] 'thirty' (Yunlinsi). Although examples are less numerous in Mawo, uvularized and plain vowels can contrast after a uvular-initial consonant cluster, e.g. /χli/ 'fall through opening', /χliʶ/ 'shady side of mountain'.

5 Summary

Heishui County Qiang vowels occur in plain–uvularized pairs, e.g. Mawo /si/ 'firewood', /siʶ/ 'rhubarb'. Ultrasound imaging shows that the highest point of the tongue is retracted during a uvularized vowel, relative to the corresponding plain vowel. Imaging data also show that the target of this gesture is the uvular region. These vowels show less lowering of the tongue body and dorsum relative to pharyngealized vowels in other languages. Shahin (2011: 618) claims that uvularization is always accompanied by some upper pharyngeal approximation. The portion of the tongue that is visible in mid-sagittal ultrasound imaging does not include the most posterior portions of the tongue. Hence, it is impossible to rule out accompanying pharyngeal approximation. Although uvularization is phonologically integrated into the vowels, uvular approximation can begin at the onset of the initial consonant.

Acoustic measurements differ systematically between plain and uvularized vowels. The latter tend to have lower values for F2 and higher values for F3-F2, both of which are indicators of acoustic backness. Uvularized vowels also tend to have higher F1 than their plain counterparts. Although the uvularized vowel does not always display higher F1 than its corresponding plain vowel, the difference F2-F1 is consistently smaller for uvularized than plain vowels; that is, the first two formants are closer together.

Acoustic and articulatory effects of Qiang vowel uvularization differ from similar phenomena that have been documented elsewhere. Nuu-chah-nulth and Kinande RTR involve retraction and lowering; however, there is no evidence for a consistent tongue lowering effect in Qiang vowel uvularization. In the fellow Sino-Tibetan languages Yi and Bai, RTR causes tense voice, whereas there is no obvious phonation difference between Qiang plain and uvularized vowels. In Ju|hoan, uvularization involves contact of the tongue dorsum followed by a fricated release of the consonant, with noise of uvular frication. However, Qiang uvularization comprises approximation of the articulators, rather than occlusion leading to frication. There may be some similarity between Qiang uvularization and emphasis in Jordanian and Palestinian Arabic, as well as tongue root phenomena in St'át'imcets. However, for Arabic and St'át'imcets, uvularization is conditioned by consonants rather than by vowels.

The nearest linguistic relatives to the Qiang languages are the Rgyalrongic languages that lie to the west of the Qiang-speaking area. In each of the three branches of the Rgyalrongic branch, a contrast between plain and 'velarized' vowels has been attested (J. Sun 2000, 2004, 2005; Lin, J. Sun & Chen 2012). In Rgyalrongic the proposed tentative label 'velarization' was motivated by auditory analysis, and by the kinesthetic impression of the position of the tongue in articulating the marked vowels in question. Furthermore, in Puxi Horpa, lowered F2 has been identified as a consistent acoustic correlate (Lin et al. 2012). A projected follow-up articulation imaging study will hopefully ascertain whether the Rgyalrongic marked vowels also turn out to involve uvularization rather than velarization, as the question cannot be decisively settled with acoustic analysis alone.

Phonological properties of uvularization include vowel harmony, which aids in the identification of plain/uvularized vowel pairs. Moreover, plain vowels in preceding syllables may assimilate this articulatory feature and turn into their uvularized counterparts. Phonotactic constraints argue for uvularization as an integral property of vowels in this language, given that uvularized vowels do not freely occur with velar initial consonants (e.g. Yunlinsi /xə/ 'exert effort', */xəʶ/). Likewise, uvular initials do not freely occur with plain vowels (e.g. Yunlinsi /χəʶ/ 'full of food', */χə/).

To aid in the discussion of uvularized sounds across the world's languages, we propose that uvular approximation be marked with /ʶ/, much as in the Voice Quality System (VoQS) of Ball et al. (1995). Secondary uvular frication could be marked with /ᵡ/, as in Miller-Ockhuizen (2003) and Miller (2007). Specifying uvularization as a secondary articulation is also important for dialectal comparisons of Arabic, as some dialects (e.g. Jordanian & Palestinian) utilize uvularization in the pronunciation of 'emphatic' consonants, while other dialects favor pharyngealization or velarization as the distinguishing articulatory feature.

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Appendix A. Forms elicited for acoustic and articulatory analyses

The values presented in Table A1 were used in the acoustic analysis for this paper. The median formant values of each of three utterances were averaged to produce the summary statistics. Forms containing initial /s l/ were also pronounced for the ultrasound imaging.

Table A1 Coronal CV forms and formant values.

Mawo					Yunlinsi				
Form	Gloss	F1	F2	F3	Form	Gloss	F1	F2	F3
/ti/	black bear	348	1978	2701	/ti/	black bear	379	1875	2813
/di/	celebrate (New Year)	324	2006	2676	/di/	press tight	288	2050	2956
/ni/	lick	326	2030	2796	/ni/	salty enough	362	2044	2844
/si/	firewood	412	1917	2636	/si/	firewood	272	1764	2770
/zi/	beat	351	2707	3397	/zi/	be burdened with work or responsibilities	319	1911	2789
/li/	thick	347	1861	2657	/li/	penis	419	1908	2664
/tiʶ/	pair (classifier)	495	1713	2785	/tiʶ/	thresh	519	1544	2403
/diʶ/	thigh	485	1774	2536	/diʶ/	thigh	486	1611	2395
/niʶ/	know	460	1468	2296	/niʶ/	know	520	1477	2528
/siʶ/	rhubarb	550	1463	2585	/siʶ/	scatter (seeds)	491	1616	2360
/ziʶ/	ladle	506	1413	2857	/ziʶ/	ladle	451	1560	2373
/liʶ/	wide	560	1323	2486	/liʶ/	wide	527	1441	2158
/tə/	understand	514	1555	2574	/tə/	understand	413	1623	2329
/də/	beans	434	1565	2142	/də/	be born	448	1676	2467
/nə/	human	501	1471	2383	/nə/	human	461	1561	2374
/sə/	leopard	462	1571	2535	/sə/	recognize	435	1494	2273
/zə/	field	456	1582	2529	/zə/	field	397	1499	2306
/lə/	roll out (dough)	479	1533	2473	/lə/	roll out (dough)	444	1646	2353
/təʶ/	brother of a man	545	1116	2802	/təʶ/	brother of a man	–	–	–
/dəʶ/	poison	502	1122	2468	/dəʶ/	poison	425	1430	2315
/nəʶ/	sleep	427	1138	2324	/nəʶ/	sleep	400	1106	2252
/səʶ/	gore (VT)	531	1189	2397	/səʶ/	gore (VT)	458	1214	2374
/zəʶ/	seed	494	1136	2540	/zəʶ/	seed	399	1238	2410
/ləʶ/	conifer	553	993	2774	/ləʶ/	conifer	400	1133	2240
/staɹa/	ax	649	1657	3117	/staɹa/	ax	736	1543	2249
/dari/	give birth (cow)	685	1546	2506	/da/	(PFV PREFIX) away from speaker	737	1526	2231
/na/	able to hear sth	762	1542	2983	/na/	EXCL meaning 'what'?	818	1649	2475
/sa/	kill	679	1577	3041	/sa/	kill	711	1514	2258
/za/	easy	645	1613	2950	/za/	easy	660	1589	2452
/la/	bring	680	1510	2596	/la/	bring	715	1609	1767

Table A1 Continued.

Mawo					Yunlinsi				
Form	Gloss	F1	F2	F3	Form	Gloss	F1	F2	F3
/taʶ/	wear (hat)	748	1161	2814	[taʶː]	flail (DEF)	766	1319	2309
/daʶ/	back and forth	735	1169	2898	/daʶ/	follow the same trails	780	1337	2351
/naʶ/	good	744	1206	2884	/naʶ/	good	689	1247	2387
/saʶ/	blood	733	1149	2757	/saʶ/	blood	760	1237	2559
/zaʶ/	scoop up	681	1180	2905	/ʁzaʶ/	collapse (of wall)	724	1280	2523
/laʶ/	wolf	711	1109	2995	/laʶ/	wolf	741	1183	2070
/tu/	rich	325	1056	2092	/tu/	valuables	298	1008	1952
/du/	door	310	1179	2160	/du/	door	319	1113	1960
/nu/	sheep	286	1140	2168	/nu/	sheep	328	1164	1980
/su/	life	391	1270	2174	/su/	life	344	1176	1962
/zu/	wait	339	1160	2076	/zu/	product	316	1175	1949
/lu/	come	366	1245	2141	/lu/	come	309	1211	1921
/tuʶ/	plow (N)	425	824	2426	/tuʶ/	plow (N)	405	870	2299
/zduʶ/	deer	420	961	2232	/duʶlə/	hell	400	956	2289
/nuʶ/	ram (N)	325	918	2233	/nuʶ-tə/	ram (N)	460	974	2408
/suʶ/	hemp	444	923	2296	/suʶ/	hemp	459	915	2587
/zuʶ/	hail	424	888	2171	/zuʶ/	hail	411	974	2348
/luʶ/	steeped porridge	403	797	2661	/luʶ/	steeped porridge	416	942	2350
					/te/	unfinished cloth (on loom)	387	1924	2898
					/de/	celebrate (New Year)	369	1986	2818
					/ne/	prick (of nettles)	383	2030	2887
					/se/	tease apart (wool)	423	1903	2640
					/ze/	beat	387	1914	2544
					/le/	thick	368	1939	2269

The Yunlinsi forms in Table A2, not listed above, were also used in the ultrasound imaging. Note that /be/ is not included in the analysis, but is given here for the sake of completeness.

Table A2 Yunlinsi labial-initial forms uttered for ultrasound imaging.

/bi/	'urine'	/bə/	'stinging flying insect'	/baʶ/	'old (of objects)'
/biʶ/	'plate'	/bəʶ/	'poor'	/bu/	'high'
/be/	'carry on back'	/ba/	'low'	/puʶ/	'five liter dry measure'

Appendix B. Distinctive consonant phonemes and clusters

Yunlinsi and Mawo simple consonant phonemes are presented in Table B1. Yunlinsi and Mawo initial consonant clusters that do not include a glide component are presented in Table B2.

In these tables, marginal phonemes and those attested only in loanwords are put in parentheses. The sound [r] occurs initially in words borrowed from Tibetan (/rəkə/ 'mystic wisdom' (both dialects)), and as an invervocalic variant of the phoneme /dʐ/: [a$^{\text{ʁ}}$ru$^{\text{ʁ}}$] < /a-dʐu$^{\text{ʁ}}$/ 'one bundle of (grain, firewood, etc.)'. However, as seen in the tables, both dialects have initial consonant clusters that begin with [r].

Table B1 Yunlinsi and Mawo consonant phonemes.

	Bilabial	Alveolar	Retroflex	Post-alveolar	Velar	Uvular	Glottal
Plosive	p p^h b	t t^h d			k k^h g	q q^h	
Affricate		ts ts^h dz	tʂ $tʂ^h$ dʐ	tʃ $tʃ^h$ dʒ			
Fricative		s z		ʃ ʒ	x	χ ʁ	h
Nasal	m	n					
Trill		(r)					
Approximant	w	ɹ		j			
Lateral approximant		ɬ l					

Table B2 Initial consonant clusters without glides.

(a) Yunlinsi

	p	b	m	t	d	s	z	n	ts	tʃ	dʒ	ʃ	ʒ	tʂ	dʐ	k	g	q
r/ɹ	rp	rb	rm		(rd)			rn	(rts)	rtʃ	rdʒ			rtʂ	rdʐ	rk	rg	
s	(sp)		(sm)	st				(sn)								(sk)		
z		zb			zd												(zg)	
k						ks						kʃ						
g							gz						gʒ					
χ/q	χp			(χt)		χs			χts	χtʃ		χʃ		χtʂ				χq
ʁ		ʁb			(ʁd)		ʁz	(ʁn)			ʁdʒ				ʁdʐ			

(b) Mawo

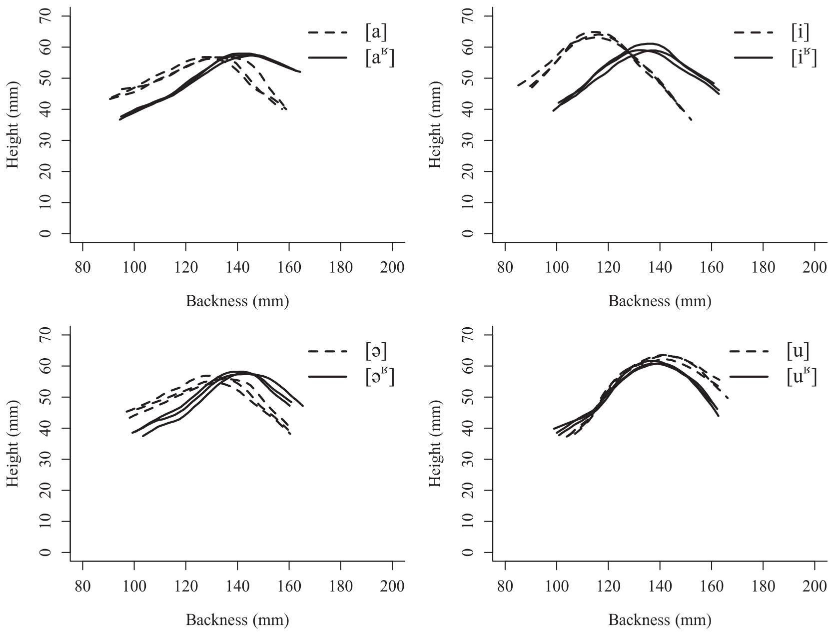
	p	b	m	t	d	s	z	n	ts	dz	tʃ	dʒ	ʃ	ʒ	tʂ	dʐ	k	g	q
r	rp	rb	rm														rk	rg	rq
s				st															
z					zd														
x						xs			xts		xtʃ		xʃ		xtʂ				
ɣ							ɣz			ɣdz		ɣdʒ		ɣʒ		ɣdʐ			
χ						χs			χts		χtʃ		χʃ		χtʂ				
ʁ					ʁd		ʁz	ʁn		ʁdz		ʁdʒ		ʁʒ		ʁdʐ			

Yunlinsi and Mawo also have clusters with glides /j w ɹ/. The inventories are similar; to avoid redundancy, in Table B3, we give the Mawo inventory.

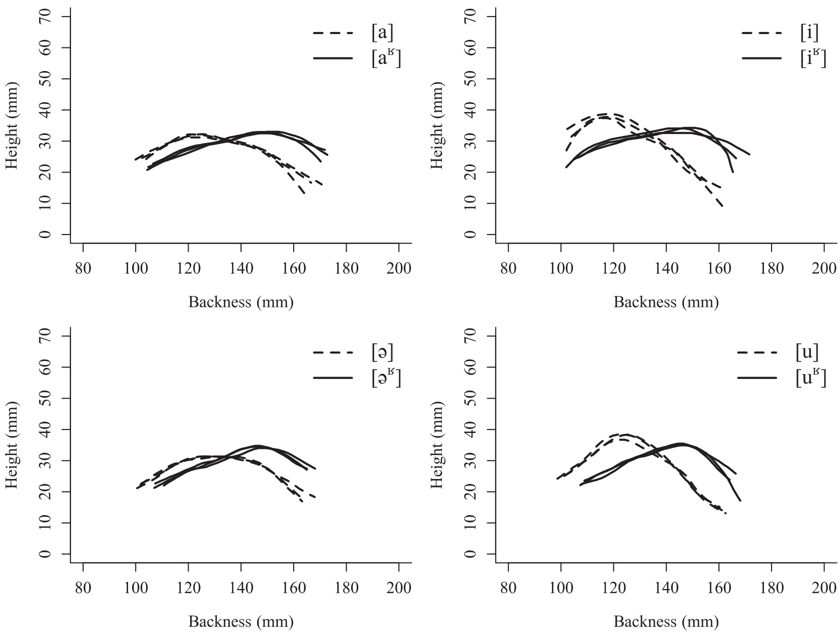
Table B3 Mawo consonant clusters with glides /j w ɹ l/.

	j	ɹ	jɹ	w	wɹ	l
p	pj	pɹ				
rp	rpj					
p^{h}	p^{h}j	p^{h}ɹ	p^{h}jɹ			
(zb)	(zbj)					
xts	xtsj					
xs	xsj					
s						(sl)
z	zj					
ɣz	ɣzj					
dʐ	dʐj					
xtʃ	xtʃj					
xʃ	xʃj					
dʒ	dʒj					
k	kj	kɹ		kw		
rk	rkj			rkw		
k^{h}		k^{h}ɹ		k^{h}w	k^{h}wɹ	
g		gɹ		gw	gwɹ	
rg	rgj			rgw		
x				xw		xl
ɣ				ɣw		ɣl
q		qɹ		qw		
rq				rqw		
q^{h}		q^{h}ɹ		q^{h}w	q^{h}wɹ	
χ				χw		χl
ʁ				ʁw	ʁwɹ	ʁl

Appendix C. Ultrasound tracings of tongue surface at vowel midpoint

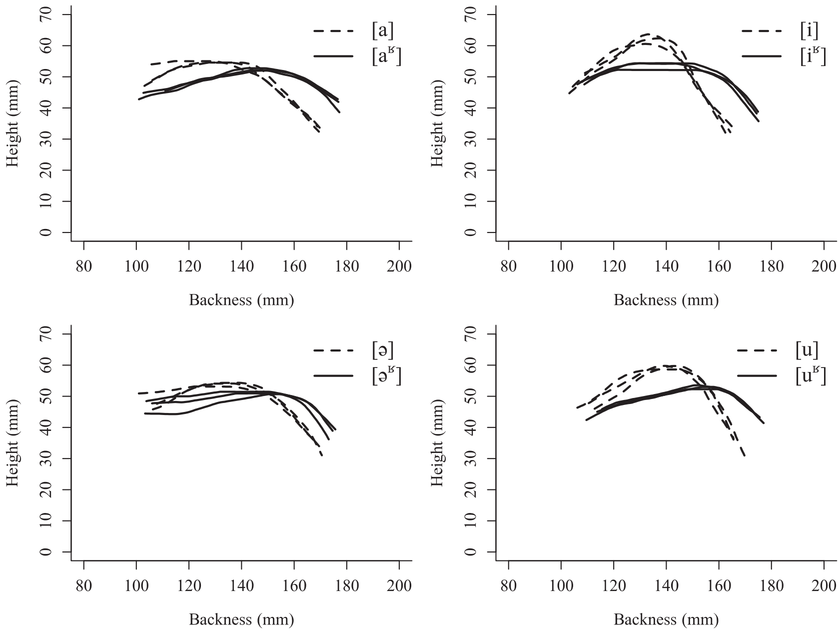


(a) The tracing of the tongue surface at the midpoint of the vowel following [b]



(b) The tracing of the tongue surface at the midpoint of the vowel following [s]

Figure C1 The tracing of the tongue surface at the midpoint of the vowel. The tongue postures of plain vowels are shown as dashed lines (CV context) whereas the tongue postures of uvularized vowels (CVR context) are outlined in solid lines. The x-axis ticks the distance (in millimeters) from the tongue tip to the tongue root (i.e. the backness of the tongue), with the tongue tip on the left. The y-axis labels the height of the tongue in millimeters.



(c) The tracing of the tongue surface at the midpoint of the vowel following [l]

Figure C1 Continued.

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