The acoustics of apical vowels in two endangered Ngwi languages

Sean Foley
UNC-Chapel Hill

1. Introduction

Syllabic fricatives or apical vowels are unique apical segments which have been attested in various Sino-Tibetan languages. Whereas most research on these segments has focused on their occurrence in Sinitic varieties, such as Mandarin (Lee-Kim 2014) and Suzhou (Wu) (Faytak 2018), these apical segments are relatively common within Ngwi (also known as Loloish), a sub-branch of Lolo-Burmese. Due to their consonant-like articulation yet vowel-like acoustics and phonotactics, considerable debate surrounds the characterization of these apical segments, with some claiming they are "syllabic fricatives", and others "apical vowels" or "syllabic approximants". Of particular issue is making sense of the acoustics-articulation mismatch that these segments exhibit if one considers them vowels, which may require an expansion of the traditional vowel space to include vowels with non-dorsal places of articulation.

As in-depth discussion on the acoustics and articulation of apical vowels in Ngwi languages is sparse, this paper will present a case study on the acoustics of apical vowels in two recently documented Ngwi languages – Naruo and Lavu – spoken in southwestern China. This study is the first such study to investigate the acoustics of apical vowels in Ngwi in comparison to the better-researched apical vowels of Sinitic. The data shows that apical vowels in both languages have similar spectral characteristics to those of Sinitic languages, while showing variability in the production of frication noise during the voicing of these segments. Both of these factors are considered within an expanded vowel space which includes vowels with a non-dorsal place of articulation. Lastly, like Sinitic, high vowels in Ngwi most likely underwent a process of apicalization or fricativization, in which they assimilate in place of articulation with the preceding sibilant. This process is seen as a form of contrast enhancement, as the apical vowels provide cues to the place of articulation of the sibilants which precede them. The current study serves as a foundation for further articulatory studies of apical vowels in Ngwi languages and aids in broadening the typology of non-dorsal vowels.

2 Background

Section 2 gives an overview of previous research on apical vowels in both Sinitic and Ngwi languages and highlights motivations for the current study. Section 2.1 details the phonetics and phonology of apical vowels and the more recent proposal for a class of "non-dorsal vowels". Section 2.2 gives a brief overview of apical vowels in Ngwi

languages, while Section 2.3 provides phonological sketches of the two languages which are the focus of the current study – Naruo and Lavu.

2.1 Apical vowels & "non-dorsal vowels"

Numerous languages within the "Sinosphere", including varieties of Chinese, such as Standard Mandarin, and Lolo-Burmese languages, such as Ngwi, have a rich inventory of sibilants, often having a three-way place contrast, while also exhibiting manner contrasts of both voiceless and voiced fricatives and aspirated and unaspirated affricates. An interesting result of the common three-way place contrast in these sibilant systems is the co-occurrence restriction on the high front vowel [i] after alveolar/dental and retroflex sibilants, e.g. *si *ʂi ɕi, prevalent in these languages. In place of [i], dental and retroflex sibilants are instead followed by voiced segments often referred to as "apical vowels" or "syllabic fricatives" (Duanmu 2007). Sino-Tibetanists traditionally transcribe these segments using the symbols [ɿ] for the dental/alveolar apical vowel and [ʅ] for the retroflex apical vowel, despite both of these symbols being absent from the IPA. Faytak (2018) states that, in reference to the apical vowels of Standard Mandarin (SM), it would be more accurate to describe them as apico-alveolar/dental (for [ɿ]) and apico-postalveolar (for [ʅ]).

Apical vowels typically have restricted phonotactics, occurring only after the preceding homorganic alveolar or retroflex sibilants. This stands in contrast to the attested "fricative vowels", which do not have restricted phonotactics and can occur after most consonants, e.g. pz^{33} 'eagle call' in Nuosu (Ngwi) (Edmondson, et al. 2017). While the terms "apical vowel" and "fricative vowel" are often used interchangeably, this paper will use the term "apical vowel" exclusively for segments which have the apical vowel phonotactics.

Attempts to characterize apical vowels have resulted in significant debate, with some referring to them as "apical vowels" and others as "syllabic fricatives" (Duanmu 2007), "syllabic approximants" (Lee-Kim 2014) or "syllabic sibilants" (Yu 1999). The segments are apical in the sense that articulatory studies carried out on apical vowels have shown that the segments are articulated with a raised tongue tip/blade (Lee-Kim 2014). The same studies have also shown that the place of articulation for apical vowels is homorganic with the preceding sibilant. On the other hand, the segments are vowel-like based on the fact that they have visible formants, usually act as an allophone of [i], and can host lexical tone contrasts. While there is general agreement on the articulation of these segments, the debate revolves more around phonological analyses of them.

Recently, Lee-Kim (2014) has argued forcibly for characterizing these segments as "syllabic approximants" on the basis of acoustic and articulatory data. Evidence against the "syllabic fricative" argument comes from the observation that speakers do not

produce any significant amount of frication noise during the voicing of the apical segments, which would be expected if they were in fact fricatives. However, other recent studies have shown that there can be significant speaker-to-speaker variability in the production of frication noise (Faytak & Lin 2015) and apical vowels in other varieties of Chinese have attested significant frication noise (Zhu 2004). Attempting to dismantle the "apical vowel" argument, Lee-Kim claims that the vowel argument creates a conflict between the articulation and the acoustics of these segments, particularly concerning their different F2 values. The more fronted segment [ɿ] has a lower F2 than the more posterior segment [ʅ], which is inconsistent with traditional notions of vowel backness, where a lower F2 indicates a higher degree of backness. On these grounds, it is claimed that the attested formant values for the segments can only be explained by them being approximants.

Dismissing the "apical vowel" argument on the basis of a conflict between the articulation and acoustics of these segments might not be viable if we consider apical vowels in within an expanded vowel space, rather than a traditional vowel space, such as that depicted in the IPA. Following a similar model to that of Esling (2005), in which the vowel space is expanded to include the influence of laryngeal musculature on vowel qualities, Faytak (2018) proposes a revision to the traditional vowel space to include vowels with a non-dorsal place of articulation. In this revision, non-dorsal vowels are divided into a range of places according to which articulator has a dominant effect on the vowel quality. Apical vowels are subsequently grouped into the coronal category, with the tongue tip/blade being the active articulator.

Articulations that involve constrictions more forward than the dorsum naturally create a larger back cavity than is typical for vowels. Considering apical vowels and other non-dorsal vowels within the expanded vowel space proposed in Faytak (2018) would naturally involve accounting for a larger back cavity as a result of the coronal constriction. However, within the general discussions of non-dorsal vowels, the general typology of apical vowels is rather limited, with a majority of the studies coming from Sinitic varieties.

Using frication as a yardstick, Faytak (2015) posits that there are two types of "fricativized" vowels: a) those with a steady-state fricative noise of relatively low intensity; b) those with high-intensity frication toward the beginning of the vowel and lower-intensity frication towards the end. If we consider that one of the goals of typology is to enable new observations to be placed within it, it is worth considering where the "fricativized" vowels of Tibeto-Burman languages fit within these two types and the general typology discussed in Faytak (2018). With this in mind, this paper serves as the first study to analyze the acoustics of apical vowels in Ngwi, a sub-branch of Tibeto-Burman.

2.2 Apical vowels in Ngwi

Outside of Sinitic, apical vowels are also widely attested in Ngwi languages (also known as Loloish). Ngwi is a sub-branch of Tibeto-Burman spoken largely in southwestern China and neighboring countries, such as Laos, Myanmar, Vietnam, and Thailand. Ngwi languages tend to show a similar inventory of sibilants to varieties of Chinese, often having a three-way place contrast. In addition, most Ngwi languages also share the tendency seen in Sinitic varieties of having a co-occurrence restriction on the high vowel /i/ following alveolar and retroflex sibilants, with apical vowels occurring in this position instead. Furthermore, similar to Suzhou (Faytak 2018) and Jixi (Shao & Ridouane 2018), a number of Ngwi languages contrast apical vowels, with restricted phonotactics, and fricative vowels, which have less restricted phonotactics.

In spite of there being only little discussion on apical vowels in Ngwi languages in general, some relatively detailed descriptions do exist. In describing the fricative vowels of Central Lisu, Tabain, et al. (2019) characterize [z̩] as a lightly fricative high central vowel and [z̩ˈ] as the "slightly stronger" fricative high central vowel. Both fricative vowels are grouped under a single phoneme [ɨ], on the basis that they function as a single phoneme. However, consistent with what has been attested for apical vowels in Mandarin, Tabain, et al. note the signifciant different in F2 values for the two fricative vowels, with the alveolar segment having a much lower F2. Differing from Mandarin though, the two segments have relatively similar F1 and F3 values. The similar F3 values is surprising given the fact that retroflex segments tend to exhibit very low F3 values (discussed below). Based on their phonotactics, the fricative vowels of Central Lisu could be described as apical vowels.

For Nuosu, Edmondson, et al. (2017) classify two front lingual fricativized vowels as voiced alveolar/retroflex fricative syllabic continuants. These segments do not have the apical vowel phonotactics and can appear after most consonants in the language, always assimilating to the place of the preceding consonant. However, unlike Faytak's description of Suzhou, fricative vowels are not distinguished by place of articulation; all are characterized as [z̩] or [z̩ˈ]. Lastly, Donlay (2015) describes a single high central apical vowel [ɿ] in Khatso, whose articulation produces turbulent airflow much like the fricative /z/. Formant values from the segment place it quite centrally compared to /i/ and /o/. In all of the examples described above, the production of frication noise during the voicing of apical vowels is described only impressionistically, which warrants more in-depth analysis to better compare apical vowels in Ngwi to those of Sinitic.

Table (1) shows a sample of Ngwi languages with apical vowels from each of the main sub-branches of Ngwi. As can be seen, Ngwi languages generally contrast at least two places of articulation in sibilants and have at least one apical vowel. Similar to Sinitic, if

a Ngwi language contrasts retroflex sibilants, then it also contrasts alveolar/dental sibilants, along with the corresponding homorganic apical vowels. In some Ngwi languages, such as Hani (Li & Wang 1986) and Khatso (Donlay 2015) the apical vowels are phonemic, and contrast with /i/ following alveolar and postalveolar/retroflex sibilants.

Despite the relative similarities between apical vowels in Sinitic and Ngwi, there has been little research done on apical vowels in Ngwi languages, particularly in comparison to Sinitic languages. As discussed earlier, there has been considerable debate on the characterization of apical vowels as their articulation and acoustic implementation may require a reformulation of the traditional vowel space. However, the typology of these segments is rather limited to due to the sparsity of research on them outside of Sinitic. Acoustic and articulatory studies on apical vowels outside of Chinese varieties, such as Ngwi, can only aid in better understanding these rather unique segments.

Language	Sub-branch	Sibilant system	Apical vowels	HV co-occurrence restriction?
Kucong (Dai & Chang 2009)	Central	s z ɕ ʑ	ɿ	Yes
Hani[1] (Li & Wang 1986)	Southern	s z (ʃ ʒ) ɕ	ɿ	No
Nasu (Chen 2010)	Northern	s z ɕ ʑ ʂ ʐ	ɿ, ʅ	Yes
Azha (Pelkey 2011)	Southeastern	s z ɕ ʑ ʂ ʐ	ɿ, ʅ	Yes

Table (1). A sample of sibilant systems and apical vowels in various Ngwi languages (fricatives only).

2.3 Phonological sketch of Naruo and Lavu

Data used in the study came from fieldwork carried out on two endangered Ngwi languages spoken in Yunnan province in southwestern China, Naruo and Lavu. Naruo and Lavu are both grouped into Central Ngwi (Foley 2020) and both languages are still relatively under-documented. Similar to what is attested for many Ngwi languages and Sinitic varities, both have a three-way place contrast in sibilants and the high vowel co-occurrence restriction after alveolar and retroflex sibilants. Table (2) shows the sibilant system shared by both languages. Similar to many Ngwi languages, Lavu and Naruo both contrast voiceless and voiced fricatives and affricates, while also contrasting unaspirated and aspirated affricates.

[1] Some dialects have a three-way place contrast, while others only have a two-way place contrast.

Figure (1) shows the vowel inventories for Naruo and Lavu. As is relevant for the current study, the apical vowels are allophones of the high front vowel /i/ in both languages, based on the fact that they are in complementary distribution with /i/ and occur only after alveolar and retroflex sibilants. Other analyses have grouped these segments into a single phoneme [ɨ], based on the formant values of the segments, which tends to place them more centrally in the vowel space. However, this paper will follow the more traditional approach in describing Ngwi languages, which, from a phonological perspective, treats the apical vowels as allophones of /i/.

	Alveolar	Retroflex	Alveolo-palatal
Fricative	s, z	ʂ, ʐ	ɕ, ʑ
Affricate	ts, tsʰ, dz	tʂ, tʂʰ, dʐ	tɕ, tɕʰ, dʑ

Table (2). Sibilant system of Naruo and Lavu.

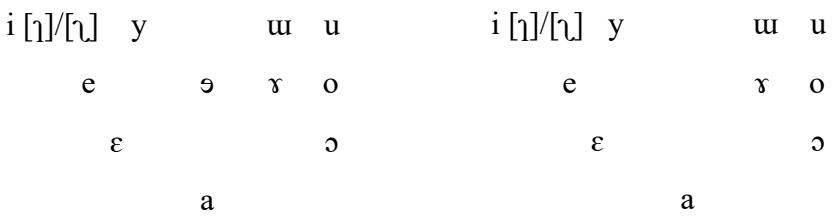

Figure (1). Vowel inventories for Naruo (left) and Lavu (right).

As mentioned earlier, both languages also have a co-occurrence restriction on the high front vowel /i/ after alveolar and retroflex sibilants. This is demonstrated in Figure (2). While the three-way place contrast among sibilants is contrastive before the low vowel /a/, the three series of sibilants do not contrast before /i/. The high front vowel can only occur after the alveolo-palatal sibilants, with the two apical vowels taking the place of /i/ after alveolar and retroflex sibilants.

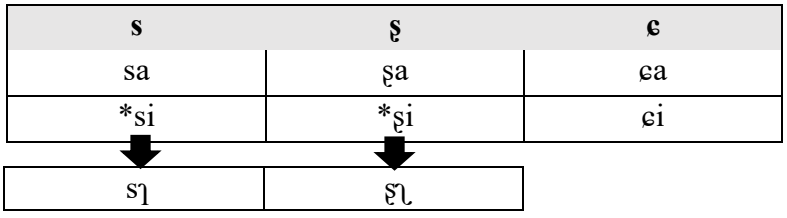

Figure (2). High vowel co-occurrence restriction in Naruo and Lavu.

In sum, the focus of the study is two-fold: a) comparing the acoustics of apical vowels in Naruo and Lavu to those of Sinitic; b) expanding the typology of apical vowels to include those of Tibeto-Burman languages.

3. Method

Lexical data was collected from three speakers of Naruo (2F, 1M) and two speakers of Lavu (1F, 1M) in the form of a wordlist with approximately 300 words elicited from the speakers. Speakers were prompted in Mandarin and responded with the equivalent in their respective language, repeating each word in isolation three times. Recordings were made using a Zoom H4N Pro digital recorder facing the speaker and mounted to a tripod for stability. All recordings were made at a sampling rate of 44.1k Hz. For Lavu, the recordings were made in a quiet room in the central office of the Lang'e village government, while for Naruo, the recordings were made in quiet rooms in the villages of Guangming and Yonghong. All of the mentioned villages are in Yongsheng County in northwestern Yunnan province.

From the collected data, lexical items containing one of the apical vowels were selected for acoustic analysis. 20 lexical items containing one of the apical vowels (10 for each) were compared to 5 items containing /i/. Example lexical items used in the study can be seen in Table (3)[2]. In all cases, the apical vowels occurred after a homorganic sibilant and /i/ occurred after an alveolo-palatal sibilant. All acoustic analysis was done using Praat (Boersma & Weenink 2021).

Target segment	Naruo	Lavu
[i]	ɕi^{21}pu^{55} 'Han Chinese'	ɕi^{21} 'new'
[ɿ]	sɻ^{33} 'firewood'	sɻ^{33} 'bowl'
[ʅ]	ʂʅ^{21} 'seven'	ʂʅ^{33}ni^{33} 'day before yesterday'

Table (3). Example lexical items used in the study.

Following the methods employed in Lee-Kim (2014), Faytak (2018), and Shao & Ridouane (2018), two acoustic properties were examined from all of the target vocalic segments. First, formant values were taken for the first three formants from the approximant midpoint of the vocalic interval. The vocalic interval was measured as starting from the onset of voicing, indicating a transition from the sibilant, to the end of the voicing period. In cases where the sibilant was voiced, the F2 of the vocalic segment was used as an indication of its onset. No coda segments were present in any of the lexical items produced by the speakers of both languages. Formant values were extracted using a Praat script.

[2] See Appendix for the full stimuli.

The F1 and F2 values of the apical vowels were also compared against the vowels /i a u/ to show their distribution in the vowel space of both languages. Formants from /a u/ were pooled across the entire wordlist mentioned above. This is important as the formant values of apical vowels in comparison to more typical vowels has been used as evidence against considering them vowels. As discussed earlier, it has been suggested that the different F2 values of apical vowels is inconsistent with their articulation, if we are to consider them vowels. The F1 and F2 values have also been used in descriptions of Ngwi languages to group the segments into single phonemes within a traditional vowel space. Based on previous research, it is expected that both apical vowels should maintain a relatively central position in the F1 x F2 space, compared to peripheral vowels like [i a u].

Second, the presence of frication noise during the voicing of the vocalic segments was measured using the harmonic-to-noise ratio (HNR), which captures the ratio between periodic and aperiodic components present in the signal. Due to their articulation, it is expected that apical vowels have a fricative noise target, and should exhibit lower HNR values than a typical vowel, [i] in this case. The midpoint HNR values were taken from the approximant midpoint of the vocalic period of each token for the target vowels. The midpoint was chosen to control for potential effects of gestural overlap, which can cause frication noise to extend from the sibilant to the onset of the following vocalic segment (Lee-Kim 2014). These values were also extracted using a script in Praat.

In addition to measuring HNR, visual inspection of both the waveform and spectrogram for the presence of frication noise during the voicing of the vocalic segments was carried out. This will allow direct comparison to the results presented in Lee-Kim (2014a) for Mandarin, in which very little to no frication noise was found. To capture frication noise at higher frequencies, the upper limit of the spectrogram was set to 15kHz.

4. Results

The results from the acoustic analysis are discussed below in sections 3.1 and 3.2.

4.1 Formant values

Table (4) shows the formant values for the apical vowels [ɿ] and [ʅ] compared to [i] for both Naruo and Lavu. The results show that formant values for apical vowels in both Naruo and Lavu are very similar to that of those attested in Sinitic languages (Lee-Kim 2014, Shao & Ridouane 2018). The retroflex segment shows higher F2 and much lower F3 values compared to that of the alveolar apical segment, while both segments have similar F1 values, albeit a high F1 value for high vowels in Lavu but not Naruo. T-tests performed on F1 and F2 show significant differences across apical vowel and [i] pairs for

both languages, with the exception of the F1 difference between [ɻ] and [i] in Naruo ($p < 0.05$). F1 values for the apical segments compared to [i] in Lavu are in line with those attested in Mandarin (Lee-Kim 2014), whereas [i] in Naruo often has an unusually high F1 and low F2 following alveolo-palatal fricatives.

			F1	F2	F3				F1	F2	F3
Naruo	[i]	(M)	393	1879	2952	**Lavu**	[i]	(M)	320	2256	3036
		(F)	480	2017	3064			(F)	407	2601	3316
	[ɿ]	(M)	458	1399	2692		[ɿ]	(M)	455	1400	3066
		(F)	504	1564	3063			(F)	558	1619	3216
	[ɻ]	(M)	428	1584	2423		[ɻ]	(M)	418	1639	2424
		(F)	502	1750	2391			(F)	518	1812	2361

Table (4). Formant values for vowels [i ɿ ɻ] from Naruo and Lavu taken from midpoint of vocalic interval.

The similar formant values exhibited by the apical vowels in Naruo and Lavu suggest a similar articulation to that attested for Mandarin. Lee-Kim (2014) states that the low F3 in the retroflex apical segments can be attributed to the large front cavity formed by the raising of the tongue blade. The absence of this large front cavity during the production of the alveolar apical segment results in the attested higher F3. Cross-linguistic studies and acoustic models of retroflex sounds also affirm this acoustic characteristic (Narayanan, et al. 1999, Stevens 1998). On the other hand, the low F2 of the alveolar segments is likely the result of the long back cavity behind the constriction at the alveolar ridge. The differences in F2 and F3 values between the two segments can be seen clearly in Figure (3) below.

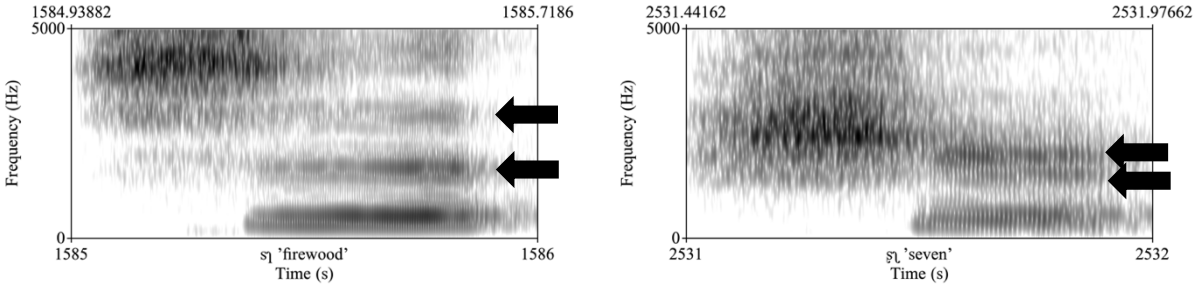

Figure (3). Spectrograms of [sɿ] and [ʂɻ] produced by a female speaker of Naruo. Arrows indicate the second and third formants.

In addition, compared to [i a u], the segments occupy a more central position in the vowel space of Naruo and Lavu (Figure 4). This is largely consistent with what has been attested in other studies on fricative/apical vowels (see Faytak 2018 for an overview). Their more central position in the vowel space is what has often lead researchers to refer to these segments as "high central vowels" or to be grouped into the segment [ɨ], as

discussed above. This is important to show as it reveals how the acoustics of these segments have led linguists into perceiving them as being more centrally articulated (compared to other vowels), when in fact they are articulated more forward in the vocal tract, e.g. those included in Figure (4). This is the source of the predicament indicated in Lee-Kim (2014), when she claims that there is an acoustics-articulation mismatch with these segments. While this mismatch led Lee-Kim to conclude that segments are not vowels, but rather syllabic approximants, it is argued in this paper that this mismatch is not prevalent if the apical vowels are considered in an expanded vowel space.

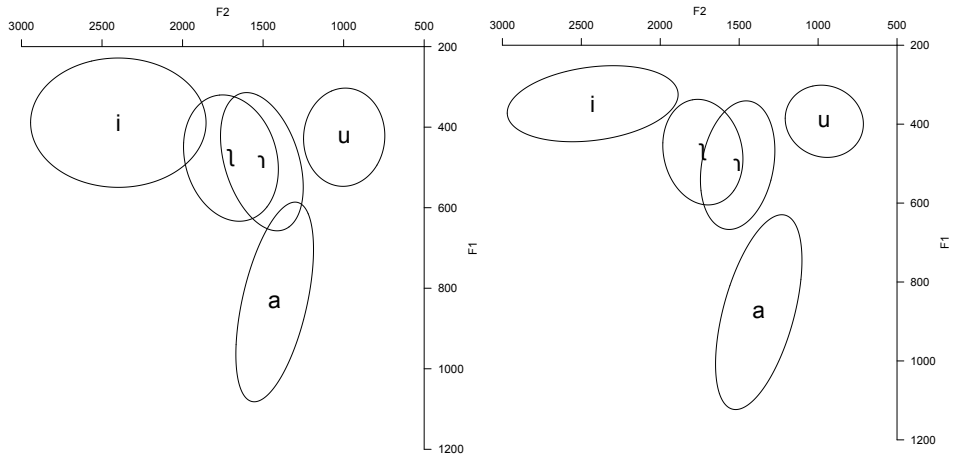

Figure (4). Apical vowels in F1 x F2 space of Naruo (left) and Lavu (right). F1 and F2 values for [ɿ ɻ] compared to that of [i a u].

4.2 Frication measurements

Figure (5) shows a comparison of the midpoint HNR values from the three target vowels for each language. The HNR values were z-scored across all speakers for both Naruo and Lavu. For each speaker, there were a few discrepant HNR values, which were attributed to potential background noise in the recording. These tokens were removed from the analysis. Overall, the HNR results are a bit surprising based on what has been found in previous studies. For Naruo, there is no significant difference between the HNR values for the three target segments, with the z-scored results showing similar spreads across the segments. The results from Lavu are even more surprising as they show [i] exhibiting lower HNR values than both apical segments. However, this may be attributed to there being significantly fewer tokens for [i] compared to the apical vowels. Having an even number of tokens across all target segments in future studies may lead to results similar to that of Naruo. Nonetheless, the results from the HNR measurements suggest that there is not significantly more aperiodic noise (frication) present during the voicing of apical vowels than in [i] in both Naruo and Lavu.

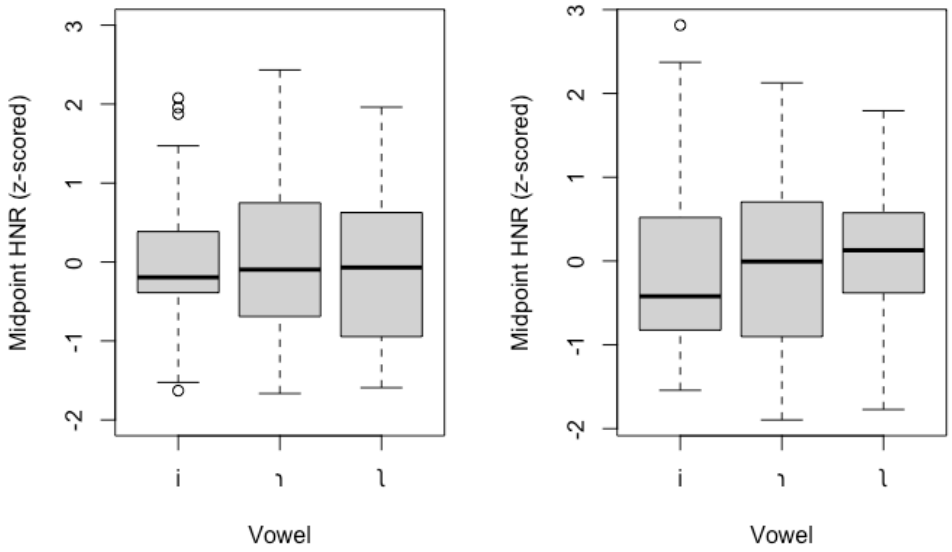

Figure (5). Z-scored harmonic-to-noise ratio (HNR) pooled across speakers by vowel for Naruo (left) and Lavu (right).

Contrary to the results from the HNR measurements, inspection of both the spectrogram and waveform reveal that the speakers of both Naruo and Lavu do produce frication noise during the voicing of apical vowels. While speakers often produce some frication during the voicing of [i] after alveolo-palatals, this frication never extends over the entire segment as it does for some instances of the apical vowels. Figure (6) shows two example spectrograms, from Naruo 'joint' tsɿ^{33} and Lavu 'bridge' (gɯ^{21}) dzɿ^{55}. In both examples, the upper limit of the spectrogram was set to 15k Hz to show frication noise at higher frequencies. It can be clearly seen that the frication noise present during the voicing of the apical segments nearly extends to both offsets. In such cases, it is unlikely that this frication noise can be attributed to gestural overlap with the preceding sibilant, but rather is the result of frication inherent to the apical segments. The two examples closely resemble the fricative vowels of Suzhou (Faytak 2018) and Jixi (Shao & Ridouane 2018), with frication at higher frequencies blocking out the higher formants. This is interesting given that, from available data, there is no evidence that Naruo or Lavu contrast coronal fricative vowels and apical vowels.

However, despite the presence of significant frication noise in the two, it is very inconsistently produced by the speakers and there is some inter-speaker variation. For example, the older female speaker of Naruo produced significant frication noise more often than the other two speakers. This could be connected to intergenerational

differences or dialectal variation as the older speaker was from a different village. Within the two Lavu speakers, there was little variation, despite a considerable age difference. Overall, examples such as those shown in Figure (6) are in the minority, with frication limited only to the onset in most instances. This might explain why the HNR measurements for both languages did not show apical vowels as having lower HNR values, as there were only a few instances of significant frication noise in apical vowels. There was one trend within the cases of significant frication noise such as shown as Figure (6). Following voiced sibilants, e.g. the spectrogram on the right in Figure (6), all speakers from both languages almost always produce frication noise that extends to the offset of the apical segment. As far as I am aware, this phenomenon is previously unattested. While an antagonistic relationship exists between voicing and frication (Ohala & Solé 2008), the production of voicing during the preceding sibilant may allow for an easier maintenance of both voicing and frication during the apical segments. Further studies on apical vowels in languages that contrast voiced and voiceless sibilants before apical vowels would be needed to confirm this.

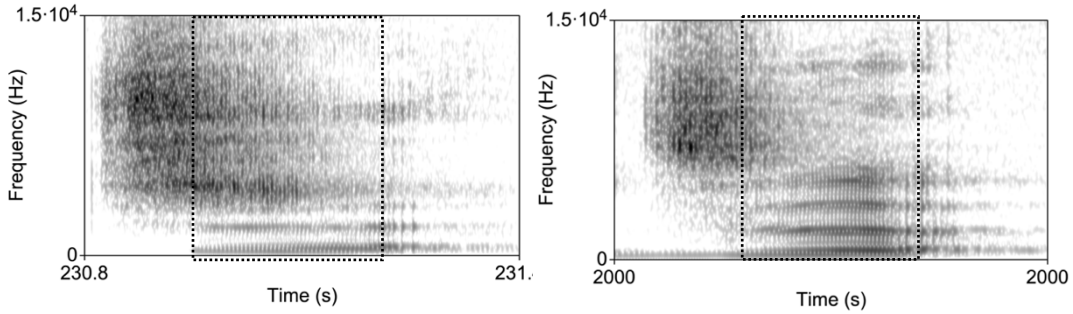

Figure (6). Examples spectrograms showing presence of significant frication noise during voicing of apical vowels. Naruo 'joint' tsɿ^{33} (left) and Lavu 'bridge' (guɪ^{21}) dzɿ^{55} (right).

5. Discussion

The apical vowels in Naruo and Lavu having similar formant values to those in attested for Sinitic suggests a similar articulation. As claimed for Mandarin, the formant values of apical vowels in Naruo and Lavu may serve as a cue to distinguish the three-way contrast in sibilant place of articulation, avoiding the palatalization of the sibilants if all were followed by [i]. The considerably different F3 values also likely serve as an important perceptual cue in distinguishing the two segments. The formant values placing the apical vowels in a central position within the vowel space of both Naruo and Lavu is consistent with previous accounts of apical vowels. As discussed above, the formant values of these segments has led to an acoustics-articulation mismatch in phonological analyses of them (Lee-Kim 2014). While their formant values place the segments more central than the peripheral vowels [i a u], previous studies have shown that they are articulation with a

more forward constriction at the alveolar ridge. This is inconsistent with traditional notions of vowel acoustic-articulation relations.

Numerous studies have shown how tongue backness (Honda 1996) or retraction (Esling 2005) is correlated with lower F2 values (see also Stevens 1998). Honda (1996) showed how the traditional F1 x F2 space follows closely with the trajectories of the tongue musculature, suggesting front vowels are articulated more forward in the vowel tract and back vowels further back in the vocal tract. While most of these studies have focused on peripheral vowels, their conclusions nonetheless suggest that a "central" vowel, e.g. [ɨ], should be articulated further back in the vocal tract than a front vowel, such as [i]. The fact that apical vowels do not follow these notions has been used as evidence against their candidacy as vowels. While the apico-alveolar segment [ɿ] is articulated more forward in the vocal tract, it tends to have lower F2 values than both the apico-postalveolar segment [ʅ] and [i]. Lee-Kim (2014) posits that we can only make sense of this mismatch if we consider these segments to be syllabic approximants, as these formant values are consistent with those attested for such segments.

However, this argument may not hold if apical vowels are considered in an expanded vowel space, which includes vowels with a non-dorsal place of articulation. Such an expansion was proposed in Faytak (2018) and includes apico-alveolar, apico-postalveolar, and labiodental vowels, among other possible places of articulation. The fact that such vowels can be articulated with a constriction more forward in the vocal tract than typical vowels, such as [i a u], requires their acoustics to be considered within an expanded space. Comparing their acoustics to those of dorsal vowels will undoubtedly lead to an acoustic-articulation mismatch. While no such model yet exists which encapsulates the formant values of non-dorsal vowels, this study aids in broadening the typology of such segments by which a model may be conceptualized.

From the typology of fricativized vowels proposed in Faytak (2015), the apical vowels of Naruo and Lavu appear to fall somewhere between both categories. While the apical segments in both languages sometimes exhibit significant frication noise that extends over nearly the entire segment, it is rather inconsistent. In most cases, frication noise is mostly limited to the onset of the segments, bringing up the question of whether this frication can be attributed to gestural overlap between the preceding sibilant and the apical vowel or is an inherent feature of the apical vowel itself. Future studies on apical vowels in Ngwi languages should better control for the potential variability of gestural overlap inherent to different sibilants. Controlling for this will allow for gaining a better insight into whether there is turbulent airflow produced during the voicing of apical vowels that cannot be attributed to the preceding sibilant.

Inconsistencies in the production of frication noise may be attributed to a variety of lingual adjustments when speakers transition from the sibilant to the apical segment, such as those discussed in Faytak & Lin (2015). However, further articulatory studies are

necessary to better understand the exact articulation of apical vowels in Ngwi languages and any potential lingual adjustments. It may also be the case that, while the apical vowels have a frication noise target, difficulty in producing both modal phonation and turbulent airflow could limit speakers' ability to produce the frication noise during the apical segments (Ohala & Solé 2008). The interesting phenomenon of apical vowels producing more frication noise following voiced sibilants is worth investigating further in other Ngwi languages and cross-linguistically.

Apical vowels being allophones of [i] in both languages may point towards the segments having arisen in Naruo and Lavu via the coarticulation of high front vowels with their onsets, similar to the process attested for Sinitic (Chen 1976). However, the question remains whether this was an independent innovation for Ngwi or the result of heavy contact with Chinese. The finding that Ngwi speakers regularly produce frication during the voicing of apical vowels may have a connection to the loss of final nasals that is common among Ngwi languages. Yu (1999) showed how there exists "intrinsic human physiological aerodynamic constraints" which disfavor adjacency of strident and nasal segments. To put it another way, there is a natural co-occurrence restriction on nasalization and frication. This suggests that the fricativization of high vowels in Ngwi may have coincided with the loss of final nasals, as has been suggested for other Tibeto-Burman languages (Chirkova & Handel 2013). Evidence for this can be seen in examples such as the reconstructed Proto-Ngwi form for 'liver' *sin² (Bradley 1979) changing to sɳ²¹ in Lavu. Based on Yu (1999), the retention of the final nasal would have blocked the fricativization of the high front vowel and this process could only have occurred once the final nasal was deleted.

6. Conclusion

In this study, an acoustic analysis was carried out on apical vowels in two endangered Ngwi languages spoken in southwestern China, Naruo and Lavu. In particular, the focus of the study was two acoustic properties, formant values and frication noise. The spectral characteristics exhibited by the target segments in the study are largely consistent with what has been attested previously. Considering these segments in an expanded vowel space may allow for making sense of the acoustics-articulation mismatch that they demonstrate. On the other hand, the study found that frication noise was inconsistently produced by speakers during the voicing of apical vowels and this variation is more considerable than previously attested. In conclusion, this is the first such study to investigate the acoustics of apical vowels in Ngwi languages and may serve as the basis for further research into these unique segments. While this study focused on the acoustics of these segments, seeing the "full picture" is only possible with the addition of future articulatory studies. It is worth noting that, while some Ngwi languages may have hundreds of thousands of speakers, many of them are endangered and may longer be spoken in the next 50 years. As such, further documentation of Ngwi languages is urgent.

References

Baron, S. 1974. On the tip of many tongues: apical vowels across Sino-Tibetan. Paper presented at the *7th International Conference on Sino-Tibetan Language and Linguistic Studies*, Oct 1974, Atlanta, GA.

Boersma, P. & Weenink, D. 2021. Praat: doing phonetics by computer [Computer program]. Version 6.1.50, retrieved 20 June 2021 from http://www.praat.org/

Bradley, D. 1979. *Proto-Loloish* (Scandinavian Institute of Asian Studies Monograph No. 39). London: Curzon Press.

Chen, M. 1976. From Middle Chinese to Modern Peking. *Journal of Chinese Linguistics, 4*(2/3), 113-277. Retrieved December 30, 2020, from http://www.jstor.org/stable/23752895

Chen, K. 2010. *Yiyu fangyan [Yi dialects].* Beijing: Minzu University of China Press.

Chirkova, K. & Handel, Z. 2013. Fricativization of high vowels and glides in Ersu, Lizu, and related languages. Paper presented at the *3rd Workshop on the Tibeto-Burman languages of Sichuan*.

Dai, Q.X. & Chang, J.Z. 2011. *Yuanjiang Kucong-hua gaikuang [An overview of the Yuanjiang Kucong language]*. Beijing: China Social Sciences Press.

Donlay, C. 2015. *A Functional Grammar of Khatso*. PhD dissertation, University of California at Santa Barbara.

Edmondson, J., Esling, J., & Ziwo, L. 2017. Nuosu Yi. *Journal of the International Phonetic Association, 47*(1), 87-97. doi:10.1017/S0025100315000444

Esling, J.H. 2005. There are no back vowels: the laryngeal articulator model. *The Canadian Journal of Linguistics / La revue canadienne de linguistique* 50, 13-44.

Faytak, M. 2015. Temporal organization of frication in fricativized vowels. *Journal of the Acoustical Society of America*. 137. 2380-2380.

Faytak, M. & Lin, S. 2015. Articulatory variability and fricative noise in apical vowels. *Proc. 18th ICPhS*, Glasgow.

Faytak, M. 2018. *Articulatory uniformity through articulatory reuse: insights from an ultrasound study of Sūzhōu Chinese*. PhD dissertation, University of California, Berkeley.

Foley, S. 2020. Naruo: an endangered Ngwi language spoken in southwestern China. Paper presented at *53rd International Conference on Sino-Tibetan Languages and Linguistics*. Denton, TX (Virtual), October 2.

Honda, K. 1996. Organization of tongue articulation for vowels. *Journal of Phonetics* 24.1, 39–52.

Lee-Kim, S. 2014. Revisiting Mandarin 'apical vowels': An articulatory and acoustic study. *Journal of the IPA* 44(3), 261–282.

Li, Y.S. & Wang, E.S. 1986. *Haniyu jianzhi [Brief description of the Hani language].* Beijing: Nationalities Press.

Narayanan, S., Byrd, D. & Kaun, A. 1999. Geometry, kinematics, and acoustics of Tamil liquid consonants. *Journal of the Acoustical Society of America* 106(4), 1993–2007.

Ohala, J. J, & Solé, M. 2008. Turbulence & Phonology. *UC Berkeley PhonLab Annual Report*, 4. http://dx.doi.org/10.5070/P74kp306rx

Pelkey, J.R. 2011. *A Phula Comparative Lexicon; Phola, Phuza, Muji, Phowa, Azha*. (SIL Language and Culture Documentation and Description, 18.) Dallas, Texas: SIL International.

Shao, B., Ridouane, R. 2018. La « voyelle apicale » en chinois de Jixi : caractéristiques acoustiques et comportement phonologique. *Proc. XXXIIe Journées d'Études sur la Parole*, 685-693.

Stevens, K. N. 1998. *Acoustic phonetics*. Cambridge, MA: MIT Press.

Tabain, M., Bradley, D., & Yu, D. 2019. Central Lisu. *Journal of the International Phonetic Association, 49*(1), 129-147. doi:10.1017/S0025100318000129

Yu, A. C. L. 1999. Aerodynamic constraints on sound change: The case of syllabic sibilants. *The Journal of the Acoustical Society of America* 105.2, pp. 1096–1097.

Appendix: Stimuli

Lavu		**Naruo**	
Transcription	**Gloss**	**Transcription**	**Gloss**
tɕʰ**i**^{55}da^{21}	lame person	ɕ**i**^{21}pu^{55}	Han Chinese
ɕ**i**^{21}	new	sɻ^{21}tɕʰ**i**^{55}	teeth
tɕ**i**^{21}	one	tɕ**i**^{21}	one
ɕ**i**^{21}	seven	ni^{21}tsɻ^{55}tɕ**i**^{21}	twenty-one
tɕʰ**i**^{21}ni^{33}	this year	tɕʰ**i**^{55}mu^{33}ʂə^{21}	bride
sɻ^{33}	firewood	sɻ^{33}	firewood
gɯ^{21}dzɻ^{55}	bridge	tsɻ^{21}(bi^{21})	joint
sɻ^{21}	bowl	dzɻ^{21}bi^{21}	raw
bu^{21}dzɻ^{33}	chili pepper	tsʰɻ^{55}	ten
tsʰɻ^{55}	ten	ni^{21}tsɻ^{55}tɕi^{21}	twenty-one
la^{55}vɯ^{55}sɻ^{55}	autonym	sɻ^{21}sa^{33}	fruit
tsʰɻ^{55}ni^{21}	twelve	zɻ^{55}mo^{33}	river
n̥^{21}tsʰɻ^{21}	beard	tu^{21}da^{33}sɻ^{21}	friend
ŋ^{21}dzɻ^{21}bia^{21}	lightning	xĩ^{55}sɻ^{21}pʰo^{21}	host
sɻ^{21}zu^{21}	small bowl	na^{33}(ku^{33}) tsɻ^{55}	show
ʂɻ^{33}n(i)ɛ^{33}	year before last	ʂɻ^{33}ni^{33}	day before yesterday
ʂɻ^{33}ni^{33}	day before yesterday	tʂʰɻ^{21}po^{21}	ram
tʂʰɻ^{21}	dog	tʂʰɻ^{21}la^{21}	wolf
dzɻ^{33}	market	ʂɻ^{33}wu^{21}ni^{33}	three days ago
a^{33}tʂʰɻ^{55}	muntjac deer	tʂɻ^{55}	sweet
ja^{21}tʂʰɻ^{55}	radish	ʂɻ^{21}	new
ʂɻ^{33}wu^{21}ni^{33}	three days ago	ʂɻ^{21}	seven
tʂɻ^{55}	sweet	dzɻ^{33}	market
ʂɻ^{33}wu^{21}niɛ^{33}	three years ago	tʂʰɻ^{21}mɤ^{33}	dog
a^{55}tʂʰɻ^{21}pu^{21}	ram	ʂɻ^{33}n(i)ɛ^{33}	year before last