AN ULTRASONIC AND ACOUSTIC INVESTIGATION OF TENSENESS IN NORTHERN YI

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Abstract Abstract This study investigates the articulation and acoustics of tense-lax contrast in two Northern Yi dialects: Suondi and Yinuo. Suondi and Yinuo have five pairs of phonologically-defined tense and lax vowels. Previous studies have suggested that the major difference between tense and lax vowels lay in phonation types and f0, while the difference in vowel quality and lingual gesture between the two types of vowels is less known. The current study describes the articulatory and acoustic characteristics of tense and lax vowels using ultrasound imaging and spectrogram analysis. The results showed that tense vowels were articulated with more retracted tongue root and higher tongue front compared to lax vowels. Acoustically, tense vowels had higher F1 and lower F2, which was caused by the lowered and retracted tongue position. The data suggests that tense-lax distinction in Northern Yi also involves advanced tongue root/retracted tongue root ([+ATR]/[+RTR]) contrast.
Keywords Northern Yi, tenseness, ultrasound imaging, acoustics, ATR/RTR

北部彝语松紧元音的超声和声学研究

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摘　要　北部彝语在音系上拥有 5 组松紧对立的元音：/i/（松）和/ɛ/（紧）；/ɯ/（松）和/a/（紧）；/o/（松）和/ɔ/（紧）；/ɿ/（松）和/ɿ̠/（紧）；/u/（松）和/u̠/（紧）。前人研究发现，松紧元音的主要声学区别存在于发声类型和基频，同时也在元音音质、时长、音强上存在一些差别。其中，松紧元音的音质区别存在争议。有研究指出，松紧元音的第一和第二共振峰存在差别，或仅在第一共振峰上存在差别；但也有部分研究指出，松紧元音音质不存在区别，或仅在个别松紧元音对中存在音质差别。本研究旨在通过超声成像数据和声学分析考察北部彝语松紧元音的发声生理特征和共振峰特征，探究北部彝语松紧元音的音质差别。超声数据可以直观地展示发音时的舌位差别，可为探究元音音质提供较为直接的证据。本文收集了一名北部彝语发音人的超声舌位数据及声学数据，以及另外五位发音人的声学数据。超声数据显示，紧元音发音时舌根后缩，舌前部（舌叶及前舌面）较低，整体舌位也较低；松元音发音时舌根较前，舌前部较高，整体舌位也较高。声学上，这位发音人的紧元音第一共振峰比松元音高，第二共振峰比松元音低，证明紧元音舌位较低且靠后，与超声数据呈现的特征一致。另外五名发音人的松紧元音声学特征与参加超声实验的发音人的声学数据特征一致。根据松紧元音的舌位特征和共振峰特征可知，彝语松紧元音的区别不仅仅在于发声类型，也同时具有类似非洲语言的舌根前伸/舌根后置（［+ATR］/［+RTR］）的区别，同时在第一和第二共振峰上都存在显著差异。紧元音舌根后缩（［+RTR］/［-ATR］），第一共振峰较高，第二共振峰低；松元音舌根靠前（［+ATR］/［-RTR］），第一共振峰较低，第二共振峰高。
关键词　北部彝语，松紧元音，超声成像，声学，ATR/RTR

1. INTRODUCTION

The contrast between tense and lax vowels is a main feature of many Tibeto-Burman languages spoken in Southwest China. One of the languages is Northern Yi language, a member of Lolo-Burmese subgroup of the Tibero-Burman family [4]. It is spoken in southern Sichuan Province and northern Yunnan Province in China [5]. Previous studies have showed that tense and lax vowels in Northern Yi language differ in a number of phonetic parameters: phonation type, vowel quality, duration, intensity, f0 and their effects on the initial consonants [13, 23, 25, 28]. Different from tense-lax distinction in Germanic languages, the differences between tense and lax vowels in Northern Yi (also called Nuosu langauge) lie mainly in phonation type and laryngeal constriction [5, 13, 23].

The most salient and well-investigated phonetic difference between tense and lax vowels is phonation type. Maddision & Ladegoged [23] suggested that tense vowels were produced with a greater glottal constriction because there was greater airflow in lax vowel. Acoustically, the amplitude difference between F0 and H2 (F0-H2) was larger for tense vowels [25]. F0-H2 is a measure that differentiates various phonation types [3, 9, 14, 15]. It has been shown to correlate with listeners' perception of breathiness [16]. Larger F0-H2 value in tense vowels indicates that the larynx is more restricted when producing those vowels. Anatomically, the production of tense vowels involves laryngeal sphincter, with the larynx raising and epiglottic root backing [6]. Tense vowels also have higher contact quotient when measured by electroglottograph (EGG), suggesting that tense vowels are creakier than lax vowels [13].

It has also been shown that tense vowels had slightly higher f0 [22, 23]. Studies using EEG showed that vocal folds opening was longer and the speed of vocal folds vibration was slower in lax vowels [28, 29]. In addition, aspirated or voiced consonants before tense vowels had prolonged aspiration and voicing [22, 23].

Tenseness in Yi Language is also realized with distinct patterns in duration and intensity. Tense vowels were shorter than lax vowels in falling tone in Liangshan Yi and in low falling tone in Xinping Yi (Southern Yi), but no durational difference was found in high and mid tones [23, 25]. Similar effect was found in intensity in Xinping Yi [25]. Tense vowels have lower intensity compared to lax vowels in low tone but not in other tones. The pattern in Wuding Yi is consistent with Liangshan and Xinping Yi. Wang and Kong [28] showed that tenseness in Wuding Yi was realized with different phonetic correlates for high and low tones. For syllables with a high tone, the distinction mainly lay in phonation type, while for syllables with a low tone, the major difference was in duration.

Another difference between tense and lax vowels is vowel quality. Shi and Zhou [25] reported that tense vowels consistently have larger F1 compared to their lax counterparts, suggesting that tense vowels were lower in tongue height. Similar results were reported in Yi spoken in Xinping and Jiangcheng [13]. Kuang [13] reported that tense vowels had higher F1 than the corresponding lax vowels, but no significant differences were found in F2. Edmondson et al. [6] showed that tense vowels have larger F1 and smaller F2, suggesting that the tense vowels were lower and backer. Besides the acoustic evidence, Lan and Wu [18] provided first articulatory data using ultrasound imaging. They compared two pairs of tense and lax vowels [ɿ ɿ̱ ʅ ʅ̱] spoken in Xide County. Based on their acoustic data and visual inspection of the raw ultrasound images, they suggested that lax vowels [ɿ ʅ] are higher and more fronted than the tense vowels [ɿ̱ ʅ̱]. The limitation of their study is that their ultrasound data is based on only two vowel pairs, and the ultrasound data are not subject to any statistical analysis. Some other studies, however, did not found vowel quality difference in Yi. For example, Maddision and Ladegoged [23] reported that tense and lax vowels did not differ in vowel quality in Liangshan Yi. Wang and Kong [28] demonstrated that in Wuding Yi, only /ɑ/ and /ɒ̱/ demonstrated some quality difference, and no difference was observed in other vowel pairs.

To clarify the vowel quality differences between tense and lax vowels in Northern Yi, the current study aims to investigate the vowel quality difference between all tense and lax vowel pairs in two Northern Yi dialects-Suondi and Yinuo using ultrasonic and acoustic data. Suondi and Yinuo are both dialects of Northern Yi. As a case study, only one native speaker of Suondi Yi was invited to the lab and recorded with ultrasound imaging. Acoustic data from five Yinuo speakers were recorded during a field trip to Leibo County (雷波县), Sichuan Province.

Table 1 Target stimuli used in the experiment

Ten vowels (5 tense and 5 lax) in /pV#/ and /pʰV#/ contexts

Vowels	Word	Gloss	Word	Gloss
i	pi33	to read	pʰi33	push aside; open
ɛ(i̱)	pɛ33	to kick	pʰɛ33	carve
ɯ	pɯ33	to exclaim	pʰɯ33	(no meaning)
a(ɯ̱)	pa33	to exchange	pʰa33	bladder
o	po33	to rummage	pʰo33	run away
ɔ(o̱)	pɔ33	to split	pʰɔ33	servant
ɿ	pɿ33	eagle call	pʰɿ33	painful
ɿ̱	pɿ̱33	to poop	pʰɿ̱33	swing
u	pu33	river deer	pʰu33	price
u̱	pu̱33	to go back	pʰu̱33	translate; counterattack

Four apical vowels (2 tense and 2 lax) in /tsV#/, /tʂV#/, /tsʰV#/ and /tʂʰV#/ contexts

Vowels	Word	Gloss	Word	Gloss
ɿ	tsɿ	hatch	tsʰɿ	save (someone from the water)
ɿ̱	tsɿ̱	crack	tsʰɿ̱	clench
ʅ	tʂʅ	urge (someone to go faster)	tʂʰʅ	becoming an orphan
ʅ̱	tʂʅ̱	pull out	tʂʰʅ̱	sprout, coming out

2. ULTRASOUNIC DATA

2.1 Participant

One male speaker of Suondi Yi participated in the ultrasound imaging. He was a native speaker of Suondi Yi, and he can also speak Mandarin and English. The speaker did not report any history of speech, hearing or mental disorder.

2.2 Stimuli

The stimuli included ten vowel phonemes which grouped as five tense-lax pairs: /i/ (lax) and /ɛ/ (tense); /ɯ/ (lax) and /a/ (tense); /o/ (lax) and /ɔ/ (tense); /ɿ/ (lax) and /ɿ̱/ (tense); /u/ (lax) and /u̱/ (tense), and two allophones of the two apical vowels ([ʅ] and [ʅ̱]) (Table 1). The 12 vowels were embedded in the /pV#/ and /pʰV#/ contexts. The bilabial stop /p/ was chosen to be the initial consonant because bilabial sounds did not have any coarticulatory influences on the following vowels. The lingual difference between tense and lax vowels can be better revealed without any influences from flanking consonants. The tense and lax apical vowels in /tsV#/, /tsʰV#/, /tʂV#/ and /tʂʰ

V#/ contexts were also included to compare the difference between the dental/alveolar apical vowel (lax apical vowel [ɿ] and tense apical vowel [ɿ̰]) and the retroflex apical vowel (lax retroflex apical vowel [ʅ], and tense retroflex apical vowel [ʅ̰]). The 28 words were read in the carrier phrase "ŋa^{33} _ _ pi^{33}" ("I read _ _").

2.3 Procedure

Ultrasound video and the audio signal were recorded with Telemed Echo B system at the Chinese University of Hong Kong. A mid-sagittal view of the tongue was obtained by placing the ultrasonic transducer under the chin of the speaker. The participant wore a light-weight headset made by Articulate Instruments Ltd. which can stabilize the ultrasonic transducer under the chin. The ultrasound videos were recorded at the frame rate of 60 fps with Articulate Assistant Advanced (AAA) software (Articulate Instruments Ltd). The participant was asked to read through the stimuli list before the experiment to make sure that he can read the words correctly and fluently. In the recording session, the stimuli were randomized and the participants were asked to read the prompt list for five times.

2.4 Data analysis

The ultrasound video and the audio signal was automatically synchronized by AAA software. The target vowels were first labelled according to the acoustic information. In the ultrasound data, each vowel contained 9 – 16 frames of images. Among the frames corresponding to the vowel, the middle frame was chosen for further analysis, with the assumption that this frame represented the target tongue shape of the vowel. The tongue curves in the selected frames were manually tracked using AAA. The tongue splines was drawn on the lower boundary of the light line because the lighter line in the ultrasound images represents the tongue-air interface (See Figure 1 as an example). Each tongue spline was exported from AAA as 124 data points for further data analysis. Smoothing spline ANOVA (SS – ANOVA) [7], contained in the R "gss" package, was used to compare tongue curves between tense ad lax vowels. SS – ANOVA can compare the differences between two or more curves, and have been widely adopted to compare tongue splines in ultrasound studies [1, 10, 19, 20, 24]. The data points exported from AAA were first converted into polar coordinates to conduct SS – ANOVA analyses, and then converted back in Cartesian coordinates for plotting. Polar coordinates were used because it has been proposed that the tongue root position was better estimated with polar coordinates instead of Cartesian coordinates [24].

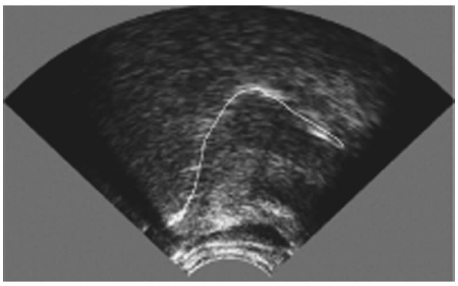
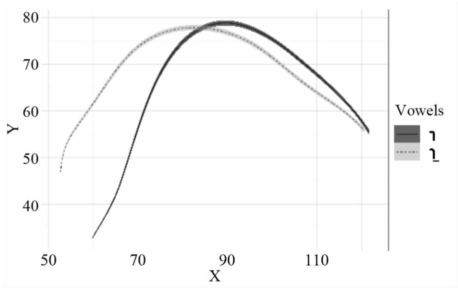
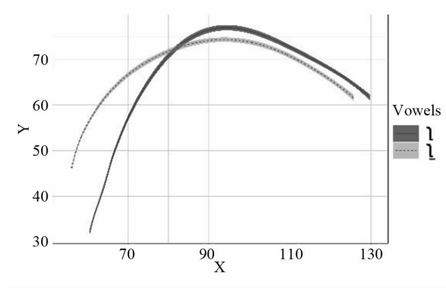


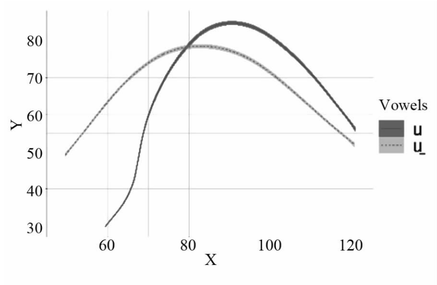
Figure 1 A raw ultrasound image of the tongue shape for vowel [ɿ] and the fitted tongue spline.



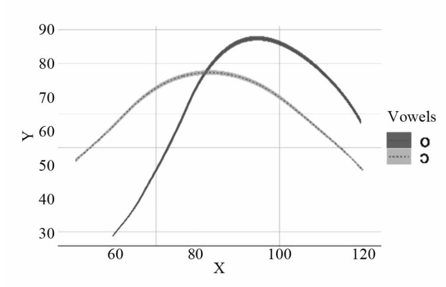
(1) Tongue shape differences between /ɿ/ and /ɿ̠/



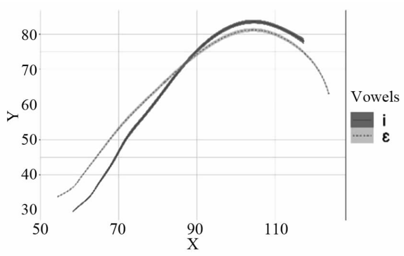
(2) Tongue shape differences between /ʅ/and /ʅ̠/



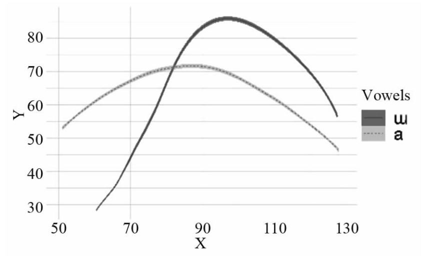
(3) Tongue shape differences between /u/ and /u̠/



(4) Tongue shape differences between /o/ and /ɔ/.

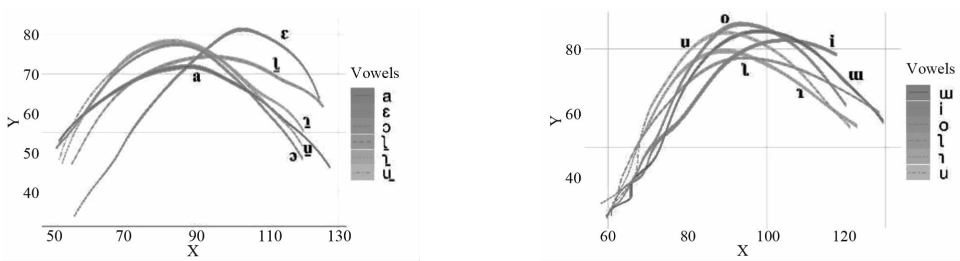


(5) Tongue shape differences between /i/ and /ɛ/.



(6) Tongue shape differences between /a/ and /ɯ/.

Figure2 The smoothing spline estimate and 95% Bayesian confidence interval for each pair of tense and lax vowels in Suondi Yi.



(1) Tongue shapes of tense vowels in Suondi Yi (2) Tongue shapes of lax vowels in Suondi Yi

Figure 3 The smoothing spline estimate and 95% Bayesian confidence interval for all vowels in Suondi Yi.

2.5 Results

The tongue shape differences between each pair of tense and lax vowels modelled by SS – ANOVA are shown in Figure 2, and the tongue shapes of all tense vowels and all lax vowels are demonstrated in Figure 3. In a SS – ANOVA figure, if the confidence intervals of two curves do not overlap, it means that the two curves are significantly different. As shown in Figure 2, for each pair of tense and lax vowels, the anterior part of the tongue in tense vowels is significantly lower than that in lax vowels. The tongue back is significantly higher and the tongue root is more retracted in tense vowels. This pattern is consistent for all vowel pairs. For high front vowel pairs, such as [ɿ ɿ̱], [ʅ ʅ̱], and /i ɛ/, the tongue height differences in the anterior part of the tongue are small but still statistically different. Except [ɿ ɿ̱] whose tongue height is similar, the tongue height of lax vowels is higher.

It seems that the position of the tongue root is the cause of the major differences between the tense and lax vowels, with tongue root in lax vowels being substantially more advanced than that in tense vowels, resulting in a fronted and higher tongue dorsum.

3. ACOUSTIC DATA

3.1 Participants

The acoustic data consists of two parts. The first part is from the male native speaker of Suondi who have participated in the ultrasound recording. Another part is from five native speakers of Yinuo (4 males and 1 female). Suondi and Yinuo are both dialects of Northern Yi. The native speaker of Suondi was recorded at the sound booth at the Chinese University of Hong Kong. Five native speakers of Yinuo (4 males and 1 female) were recorded with a Zoom recorder in a hotel room at Leibo County, Sichuan Province. All the speakers were in their mid-forty or mid-fifty, and they all spoke their native dialect on a daily basis. They did not report any history of speech, hearing or mental disorder.

3.2 Procedure, stimuli and data analysis

The stimuli and the carrier phrase are the same as mentioned in Section 2.1 except the word /p^{h}ɯ^{33}/. This word is omitted in acoustic recording because this word has no meaning in Northern Yi. The participants were instructed to translate the words they hear in Mandarin or Sichuan dialect into their own dialect (Yinuo or Suondi) and then say the word out loud. They were asked to practice the words until they can fluently pronounce each word. The stimuli were randomized and the participant was asked to repeat the prompt list for five times. The two sets of acoustic data (Yinuo or Suondi) are analyzed individually. As the number of speakers in the current study is rather small, pair-wise t-tests are used to compare the differences in F1 and F2 between each pair of tense and lax vowels.

3.3 Results

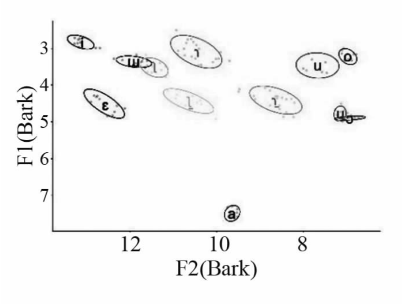
The first and second formant frequencies of all vowels in Yinuo and Suondi are summarized in Table 2 and Table 3. Figure 4 shows the vowel space of Suondi vowels. In the vowel chart, the five tense vowels are lower and to the right of their corresponding lax vowels. This pattern is consistent for all vowel pairs except /o/ and /ɔ/. For /o ɔ/ vowel pair, the lax vowel /o/ had a significantly higher F1 than the tense vowel /ɔ/ ($t(12) = -44.384$, $p < 0.001$), but no significant difference was found in F2. For other pairs of tense and lax vowels, the F1 of tense vowels was significantly higher than that of lax vowels ([ɿ] − [ɿ̱]: $t(38) = -16.919$, $p < 0.001$; [ʅ] − [ʅ̱]: $t(16) = -10.829$, $p < 0.001$; /u/ − /u̱/: $t(13) = -17.226$, $p < 0.001$; /i/ − /ɛ/: $t(12) = 20.882$, $p < 0.001$; /ɯ/ − /a/: $t(13) = 72.736$, $p < 0.001$). The F2 of tense vowels was significantly lower than that of lax vowels except the /o/ − /ɔ/ pair ([ɿ] − [ɿ̱]: $t(38) = 15.28$, $p < 0.001$; [ʅ] − [ʅ̱]: $t(15) = 6.722$, $p < 0.001$; /u/ − /u̱/: $t(8) = 5.143$, $p = 0.001$; /i/ − /ɛ/: $t(17) = -5.203$, $p < 0.001$; /ɯ/ − /a/: $t(11) = -24.229$, $p < 0.001$).

Figure 5 illustrates the vowel space of Yinuo vowels. Lax vowels are above and to the left of their tensed counterparts in the vowel chart for /ɯ/ − /a/, /ɛ/ − /i/, [ɿ] − [ɿ̱], and [ʅ] − [ʅ̱]. The t-tests showed that the F1 of tense vowels was significantly higher than that of the corresponding lax vowels ([ɿ] − [ɿ̱]: $t(119) = -21.216$, $p < 0.001$; [ʅ] − [ʅ̱]: $t(64) = -14.299$, $p < 0.001$; /i/ − /ɛ/: $t(54) = 19.787$, $p < 0.001$; /ɯ/ − /a/: $t(36) = 20.972$, $p < 0.001$; /u/ − /u̱/: $t(64) = -12.529$, $p < 0.001$; /o/ − /ɔ/: $t(95) = -10.448$, $p < 0.001$). The F2 of tense vowels was significantly lower than that of lax vowels in /ɯ/ − /a/, /ɛ/ − /i/, [ɿ] − [ɿ̱], and [ʅ] − [ʅ̱] ([ɿ] − [ɿ̱]: $t(156) = 7.027$, $p < 0.001$); [ʅ] − [ʅ̱]: $t(63) = 3.967$, $p < 0.001$; /i/ − /ɛ/: $t(84) = -2.168$, $p = 0.033$; /ɯ/ − /a/: $t(39) = -2.706$, $p = 0.010$). No significant difference was found in F2 between /u/ and /u̱/. Contrary to other vowel pairs, the F2 of /ɔ/ was significantly higher than /o/ ($t(94) = -5.848$, $p < 0.001$). In the vowel chart, the vowel /o/ is above but to the right of the tense vowel /ɔ/.

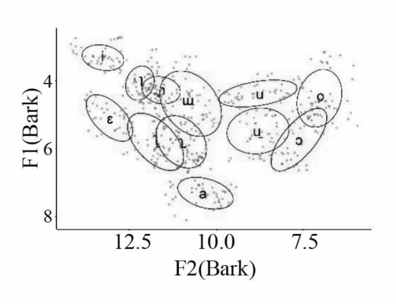
To summarize, the tense-lax contrast is realized similarly in Suondi and Yinuo, with tense vowels having higher F1 and lower F2. This pattern is consistent for all front vowels, but not for the high back vowel /o/ and /ɔ/. The tense vowel /ɔ/ has higher F2 compared to its lax counterpart /o/.

Table 2 First and second formant frequency of Suondi Yi in Hertz and Bark.

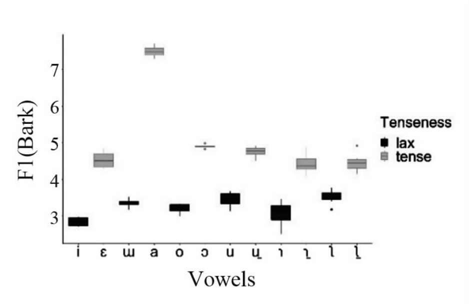
IPA	F1		F2	
	Hz	Bark	Hz	Bark
i	282	2.84	2031	13.1
ɛ	456	4.53	1876	12.6
ɯ	332	3.36	1700	11.9
a	837	7.49	1201	9.66
o	317	3.21	762	6.98
ɔ	498	4.9	756	6.93
u	342	3.45	865	7.67
u̱	482	4.76	786	7.15
ɿ	306	3.09	1363	10.5
ɿ̱	443	4.41	1026	8.67
ʅ	349	3.52	1582	11.4
ʅ̱	448	4.45	1401	10.6



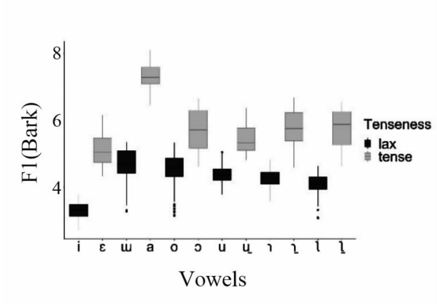
(1) The vowels of Suondi Yi.



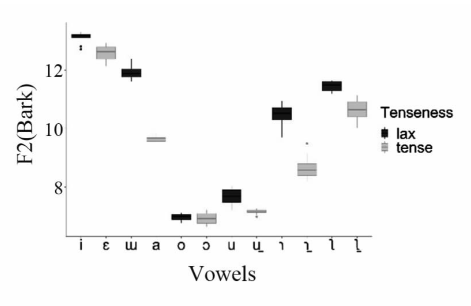
(1) The vowels of Yinuo Yi.



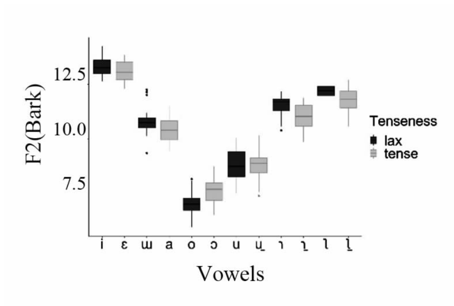
(2) The F1 of Suondi Yi vowels.



(2) The F1 of Yinuo Yi vowels.



(3) The F2 of Suondi Yi vowels.



(3) The F2 of Yinuo Yi vowels.

Figure4 Vowels in Suondi Yi. The upper panel demonstrates the vowel space of Suondi Yi. The middle and lower panel show the F1 and F2 of all tense and lax vowels in Suondi Yi.

Figure 5 Vowels in Yinuo Yi. The upper panel illustrates the vowel space of Yinuo Yi. The middle and lower panel show the F1 and F2 of all tense and lax vowels in Yinuo Yi.

Table 3 First and second formant frequency of Yinuo Yi in Hertz and Bark.

IPA	F1		F2	
	Hz	Bark	Hz	Bark
i	326	3. 29	2097	13. 3
ɛ	524	5. 11	2032	13. 1
ɯ	463	4. 57	1451	10. 8
a	811	7. 31	1355	10. 4
o	449	4. 45	768	7
ɔ	600	5. 74	859	7. 62
u	441	4. 39	1045	8. 76
u̱	567	5. 48	1058	8. 84
ɿ	427	4. 27	1612	11. 6
ɿ̱	604	5. 77	1492	11
ʅ	403	4. 03	1770	12. 2
ʅ̱	601	5. 75	1665	11. 8

4. DISCUSSION

The ultrasound data in the current study demonstrated that the tense vowels are articulated with more retracted tongue root and lower tongue front compared to the corresponding lax vowels. Acoustically, in general, tense vowels have higher F1 and lower F2 thanlax vowels. This is consistent with the results reported in previous acoustic studies [6, 25]. The ultrasound data also complements previous study by providing direct evidence on the lingual differences between tense and lax vowels.

Previous studies using laryngoscopy have shown that Yi tense vowels were articulated with raised larynx and constricted epiglottic root [21]. Our ultrasound images complemented previous data by showing that the articulation of tense vowels also involves retracted tongue root. To articulate tense vowels, the tongue is retracted, with the posterior part of the tongue raised and the anterior part lowered, while the epilaryngeal tube is constricted and the larynx is raised. When articulating the tense vowels, there is a great constriction and a tension in tongue root and throat.

Our articulatory data also showed that tenseness distinction in Northern Yi can be related with advanced tongue root (+ATR) and retracted tongue root (+RTR) contrast. The ART and RTR contrast is often seen in African languages [17]. It has been shown that the articulation of ART usually involves the widening of lateral pharynx walls and the lowering of larynx, whereas the production of RTR vowels involves pharyngeal constrictions and larynx raising [21, 27]. This pattern is similar to the articulation of tense and lax vowels in Yi. In Northern Yi, the tense vowels has more retracted tongue root, while the lax vowel is characterized with the advanced tongue root. According to Ladefoged and Maddieson [17], the major difference between +ATR/+RTR contrast and tense-lax contrast is that tongue height is not correlated with tongue root position in +ATR/+RTR contrast. For example, the difference between Akan +ATR/+RTR vowels in tongue height is rather small compared to the changes in tongue root and pharyngeal region. In Northern Yi, the pattern is mixed. The tongue root position and the tongue height seems to be related for some vowel pairs, such as /u u̱/, /ɯ a/, and /o ɔ/. But for high front vowels and apical vowels, such as [ɿ ɿ̱], [ʅ ʅ̱] and /i ɛ/, the tongue height difference between tense and lax vowels is much smaller than the difference in tongue root, which resembles the pattern of +ATR/+RTR contrast in African languages.

Our acoustic data confirm that tense and lax vowels have distinct vowel quality. Previous studies had controversial results regarding the acoustic correlates of tenseness. Edmondson et al. [6] and Shi and Zhou [25] suggested that there were differences in F1 and F2 between tense and lax vowels. On the contrary, Maddison and Ladefoged [23] found no difference in vowel quality, while Wang and Kong [28] found formant differences only for the /a/ and /ɒ/ vowel pair. Our acoustic result is consistent with Edmondson et al. [6] and Shi and Zhou [25]. We found vowel quality difference between tense and lax vowels in both F1 and F2. According to the Perturbation Theory [26], higher F1 represents lower tongue position, and lower F2 indicates that the tongue is backer. This prediction is consistent with our articulatory data where we found lower and backer tongue position for tense vowels.

The pattern of F2 for /o/ and /ɔ/ pair is opposite to other tense-lax vowel pairs, with higher F2 for the tense vowel /ɔ/ and lower F2 for the lax vowel /o/. According to Panel 4 of Figure 2, the tongue position of the lax vowel /o/ is more fronted, suggesting that it should have higher F2. One possible explanation for it is that the F2 of /o/ is lowered due to the lip rounding. The Perturbation Theory suggests that F2 will be lowered as the front resonating cavity is enlarged by retracting the tongue or protruding the lips[26]. It is possible that F2 of /o/ is lowered because of the extra lip protrusion in /o/. This hypothesis, however, needs to be tested in future experiment examining the lip movements of Yi vowels. Another limitation of the current study is that the number of speakers is rather small for both ultrasound imaging and acoustic analysis. Data from more speakers are needed to confirm the findings of the current study.

One unexpected pattern in the vowel chart is that /u/ vowel is to the left of /o/ in both Yinuo and Suondi, and the vowel /u/ has a higher F2 than /o/. However, in the ultrasound data, the tongue position of vowel /u/ is backer than that of /o/ (Figure 3), which means /u/ should have a smaller F2. This mismatch between articulatory and acoustic measures might be caused by the lip protrusion in the /o/ vowel as well. This possibility also needs to be confirmed in future studies with lip measures and a larger number of participants.

5. CONCLUSION

In summary, this study examined the articulatory and acoustic characteristics of tenseness in Northern Yi using ultrasound imaging. The articulatory data showed that for all five pairs of tense and lax vowel phonemes, as well as one pair of retroflex apical vowel allophones, tense vowels are articulated with more retracted tongue root and lower tongue front, while lax vowels are articulated with advanced tongue root and higher tongue front. The acoustic consequence of the tongue retraction is that F1 is increased and F2 lowered. It suggests that the phonetic correlates of tenseness in Yi lie not only in phonation types or laryngeal constriction, but also in vowel quality. The tense-lax contrast in Northern Yi also involves advanced tongue root ([+ATR]) and retracted tongue root ([+RTR]) contrast.

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