INTERSPEECH 2020
October 25–29, 2020, Shanghai, China

Interaction of Tone and Voicing in Mizo

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Abstract

Since the production of fundamental frequency and voicing is determined by the tension in the vocal folds, it is noticed that VOT is affected by the F0 in tone languages. Similarly laryngeal contrasts also affect the F0 of tone. This work studies the interaction between tone and voicing in a lesser-known tone language, Mizo. Mizo has eight stops, that can be categorized into three laryngeal contrasts namely, voiced, voiceless unaspirated, and voiceless aspirated. In the current work, we look into CV syllables produced with the eight Mizo stops with all five vowel categories of the language, produced with four distinct tones in Mizo. The results show a predictable effect of onsets on the F0 of tone and weak effect of tone on VOT duration.

Index Terms: Mizo, Tibeto-Burman, Tone language, VOT, Voicing, Tone VOT interaction

1. Introduction

Mizo is a tone language with four lexical tones with a three−way laryngeal contrasts in stop consonants. While tone languages, such as Mizo, use fundamental frequency (F0) to cue lexical tones, laryngeal contrasts in the consonants preceding a vowel onset still may induce their effects on the F0. Such onset specific F0 effects are known as co-intrinsic pitch (CF0) and they aid the discrimination of voicing differences in the onset [1, 2]. Recent investigation with tone languages have seen that CF0 behaves slight differently in those languages. It was noticed that in tone languages, the effect of CF0 is more prominent in citation forms than in connected speech. Additionally, the effects are more noticeable in tones with higher F0 [2].

Voice Onset Time (VOT), the interval between the release of stop and the onset of voicing, is one of the primary acoustic cues to differentiate laryngeal contrasts in a language [3]. The perception of voicing contrasts, on the other hand, is reported to use not only VOT, but also the combination of the F1 and F0 at vowel edges, the duration of the closure, and the continuation of low-frequency energy at boundary of vowels and consonants [4]. The beginning of VOT is determined by the articulatory release of the stop and the beginning of vocal fold vibration marks the end of VOT. Generally, voiced stops have significantly longer negative VOT than the voiceless stops. In case of the voiceless stops, aspirated stops have longer positive VOT than unaspirated stops. It is also seen that VOT length is negatively correlated with the frontness of the place of articulation (POA) [1, 5]. Voicing contrast is a phonatory phenomenon, where voicelessness involves nil phonation, whereas, voicing involves modal phonation of the vocal cords. Apart from phonation contrasts, vocal cords are also responsible for the production of F0 [6]. Hence, it is interesting to see how the tone production and laryngeal contrasts correlate with each other in a tone language, as in such languages both VOT and tone need to be controlled by a speaker of a tone language.

The aerodynamic explanation for the effect of tone on VOT suggests that the increase in F0 is associated with longer VOTs [7, 8, 9]. The aspirated stops with high tones in Tibetan are also reported to have longer VOT than the low toned aspirated stops [10]. Contrary to such reports, it is observed that the production of voiceless stop with mid or low F0 in English, has longer VOT than when produced with high F0. However, pitch effect on VOT was not significant in voiced stops [11]. The same phenomenon was observed in Korean and English where the increase in pitch during the production of aspirated stops trigger shorter VOT [7]. The same work also found that there was no significant difference for pitch variation effect on VOT in the tense and voiced stops in Korean and the voiced stops in English. It is assumed that a lower tone having longer VOT could be due to a greater downward movement in the larynx that requires more time for the air to release from the oral cavity [12].

The effect of tone on VOT is attested in Mandarin where the high-falling tone correlates to shorter VOT in comparison to mid-rising and falling-rising tones. The rising contour in the rising-falling tones increase the tension in the vocal folds and delay the onset of vocal folds vibration, resulting in longer VOT [13]. A shorter VOT is observed in higher tones compared to the lower tones in Cantonese [14, 12]. It is also reported that Cantonese tones with rising contours have longer VOT as in Mandarin [14]. The negative correlation between tone height and vowel duration is also reported for 20 out of 26 languages with level tones, the remaining 6 languages are assumed to have contours tones [15].

The discussion above indicates that even in the case of tone languages, there is a strong voicing and tone correlation. While voicing induced CF0 affects the initial pitch contour of tones in tone languages, tones also induce tone specific variation in VOT of the pretonal stop consonants [3, 12, 13, 14]. Hence, in the current work, we explore the tone and VOT correlation in Mizo, a lesser-known tone language. The present study focuses on how the VOTs of voiced unaspirated, voiceless unaspirated, and voiceless aspirated stops in Mizo differ in terms of tone. It also looks into the effect of tone on each of the consonantal stops in Mizo and investigates whether Mizo as a tone language conforms to the findings reported for other tone languages. Additionally, this paper also explores the effect of voicing types on the pitch contour of the four tones in Mizo. The remaining part of the paper is arranged as follows: A short description of Mizo language and the methodology used in the study are described in Section 2. Section 3 presents the results of the study and finally Section 4 discusses and concludes the study.

http://dx.doi.org/10.21437/Interspeech.2020-2695

Table 1: *The minimal set of the four lexical Mizo tones.*

IPA	Tone	Orthography	Meaning
/t^haŋ/	Falling	thang	'gone away'
	High	thang	'known'
	Rising	thang	'a trap'
	Low	thang	'greasy'

2. Methodology

2.1. Mizo language

Mizo (ISO 639-3 code: lus) [16] is spoken by the Mizo tribe residing largely in the province of Mizoram in the Northeast of India. It belongs to the Kuki-Chin subgroup of the Tibeto-Burman language family with $830,846$ speakers. Mizo has 30 consonantal phonemes out of which 13 are plosives [17]. The present study deals with only 8 stops categorized as voiced, voiceless unaspirated and voiceless aspirated stops which include /b, d, p, t, k, p^h, t^h, k^h/. There are 5 vowels in Mizo, namely, /a, e, i, o, u/ [18, 17, 19]. These five vowels have a two-way durational contrast in the language [17, 19]. Mizo is a tone language with four distinct tones, namely, falling, low, high and rising tone [17, 18, 19, 20, 21, 22]. Table 1 shows a minimal set of Mizo tones with a four−way tonal contrasts.

Standard Mizo orthography is based on the Roman script and it does not indicate all four tones in the language. Usually, the high tone or a falling tone occurring in a longer rime may be marked with a circumflex. Additionally, a high tone occurring in a longer rime may also be indicated using an acute accent. Nevertheless, the use of these diacritics are not consistent in indicating tones in the Mizo orthography.

2.2. Speakers

The participants in the study were 5 male and 5 female Mizo native speakers who were born and brought up in Mizoram. None reported any hearing and speech disabilities. The average and the standard deviation of the age of the 10 participants are 27 and 7 years respectively. All of them could understand English. The Mizos are aware of the presence of tones in their language, however, tones are not learnt explicitly during formal institutional education. Due to this, although the participants naturally produce the four Mizo tones in their speech, they are not consciously aware of the distinctions among these tones.

2.3. Materials and recording procedures

The 8 Mizo stops, namely, /b, d, p, t, k, p^h, t^h, k^h/ were produced in CV syllables. Each stop is followed by the 5 Mizo vowels - /a, e, i, o, u/ assigned each with the 4 Mizo tones (falling, high, low, rising) resulting in 160 nonwords. The CV nonwords are considered in the present study since we were unable to find CV syllables with all possible contrasts in vowels and tones. As we used nonwords to capture tone production in different laryngeal contrast conditions, each tone target was preceded by a real Mizo word in the syllable /bel/ (falling-'to stick', high-'pot', low-'to rely', rising-'thorough') to cue the correct tone while producing the nonword syllables.

The tokens in the data list were presented randomly on a computer screen. As mentioned earlier, the tone to be produced on each CV non-word was cued by a real word in the syllable /bel/. In order to induce the correct lexical tone on the /bel/ syllable, the computer screen displayed the meaning, in English, corresponding to the /bel/ syllable with a particular tone. Following that, the nonword syllable would appear on the screen and the speakers were instructed to produce it with the tone of the preceding /bel/. In this manner, each nonword appeared randomly for three times. The recording was carried out in a quiet room in Mizoram using a TASCAM DR 100 MK II voice recorder connected to a Shure SM - 10 unidirectional head-mounted microphone. The average time taken for the recording by each participant was one hour.

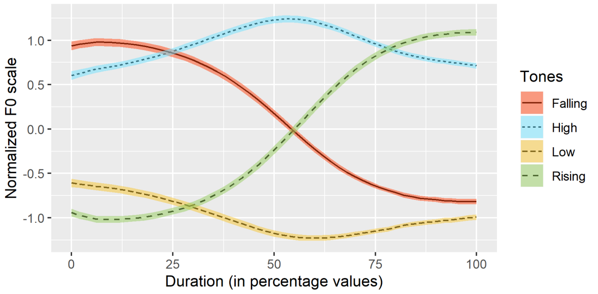

Figure 1: *Mean and standard error of normalized F0 contours of Mizo tones in nonwords.*

After the recording was over, the first author of this paper, a Mizo native speaker, listened to the 4800 tokens produced by 10 speakers and detected 11 tokens that were mispronounced with wrong tones. Hence, only 4789 tokens were considered out of 4800 for the study. Further, to confirm if the tones produced on nonword syllables are similar to the actual Mizo tones, the F0 contours were plotted as seen in Figure 1. The figure clearly shows that the four lexical tones closely resemble the F0 contours of Mizo tones reported in the previous studies [20, 21, 23].

2.4. Acoustic and statistical analysis

The speech recordings were transferred in a computer for analysis. Segmentation and annotation at the word level was done using Praat 6.0.21 [24]. Afterward, the speech files were extracted at the word level and were subjected to automatic VOT detection using Dr. VOT [25]. Dr. VOT marked the VOT boundaries for three−way laryngeal contrasts in Mizo. The marked boundaries were manually checked for errors and it was found that about 35% of the boundaries were wrongly marked by the tool. There were three observations we made about VOT boundary marking by Dr. VOT. Firstly, voiceless aspirated stops are labelled as NEG-VOT instead of POS-VOT, although the automatically derived boundaries have positive VOT. Secondly, voiced stops are annotated as POS-VOT and the VOT boundary begins at the release of the burst and ends at the beginning of the vowel. Thirdly, voiceless unaspirated stops are segmented and annotated correctly in comparison to voiceless aspirated and voiced stops.

The first author cross-checked the Dr. VOT derived VOT boundaries and annotations and corrected the errors manually. Afterward, VOT values in milliseconds were extracted using a Praat script and were exported in a spreadsheet for further analysis. In order to eliminate the speaker effects on F0, the raw F0 values were normalized using z-score normalization [26]. Equation 1 is used for the normalization where μ is the mean F0, and σ is the standard deviation of the F0 values considered for mean F0. Normalization of F0, plotting of the data, and descriptive and investigative analyses were done in R[27, 28].

$$x = \frac{x - \mu}{\sigma} \tag{1}$$

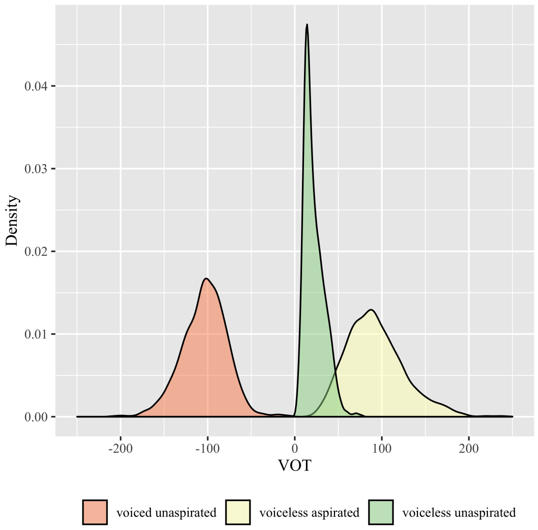

Figure 2: *Density plot of VOT in three voicing types in Mizo.*

3. Results

The VOT extracted from all the Mizo tokens were analyzed for their duration and their distributions are plotted in Figure 2. The figure shows a normal distribution of the VOT values across all tone, vowel, and POA. From Figure 2, it is evident that voiced stops have large negative VOT and voiceless aspirated stops have large positive VOT. On the other hand, voiceless unaspirated stops have short positive VOT (median = 19 m.s.)

3.1. Pretest on tone duration

A previous study on Mizo tone duration concluded that only the falling tone is significantly different from the other three tones in terms of duration [20]. This study was conducted with data from a single Mizo speaker and vowel duration contrasts was not controlled. Hence, to confirm the claims reported in the previous study, we analyzed data from 10 Mizo speakers (not the same speakers as in this study) producing the syllable /vai/ in four different tones resulting in four distinct lexical items in the language. Each Mizo speaker produced each of the four lexical meanings three times, resulting in the total number of 120 tokens (10 speakers x 4 /vai/ x 3 iterations). However, three tokens were mistakenly skipped by the speakers while reading the data list. The duration of the remaining 117 tokens is shown in Figure 3, categorized by tones.

We constructed a Linear Mixed Effects (LME) model for the duration of tones in Mizo. Tone type was considered as fixed factor and speaker, gender and iteration were considered random factors. The LME model was created using the *lme4* package on R[27, 28]. The *step()* function of the *lmerTest* package [29] was used to perform backward elimination of random and fixed effects of the LME model resulting in a reduced model with tone type as fixed factor and speaker as a random factor. To estimate the significance of tone types, the LME model was subjected to an analysis of the deviance test using a Wald χ^2 test on R using the *car* package. The Wald χ^2 test yielded a non-significant p-value, confirming no interaction between tone types and tone duration [$\chi^2(3, N = 117) = 4.5, p = 0.21$]. Further, we subjected the reduced LME model to a Bonferroni test to see pairwise contrasts among tone types, using the *emmeans* package on R [30]. However, none of the pairs showed a significant contrast in terms of tone duration. Hence, we conclude that there is no significant duration difference among the four Mizo tones. This information is important for the current study as any duration difference in tone categories are now confirmed to be not tone category induced differences.

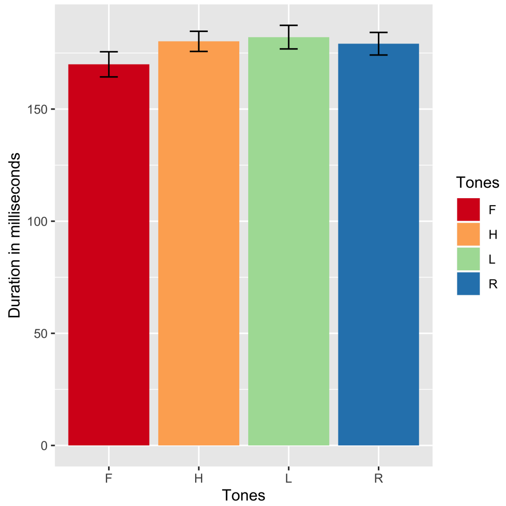

Figure 3: *Mean duration of four Mizo tones in /vai/.*

Table 2: *Result of pairwise comparison of initial F0.*

Contrast	Estimate	SE	df	*t* ratio	*p* value
Voiced Unaspirated - Voiceless Aspirated	-0.482	0.0211	4785	-22.823	<.0001
Voiced Unaspirated - Voiceless Unaspirated	-0.329	0.0211	4785	-15.558	<.0001
Voiceless Aspirated - Voiceless Unaspirated	0.153	0.0189	4785	8.116	<.0001

3.2. CF0 effect on tone

To see the effect of the stop consonants on the following pitch contour, we plotted the pitch contours categorized by eight stops in the onset position. The pitch contours for four Mizo tones are presented in Figure 4. As seen in Figure 4, we can see the effect of onset types on the F0 contour. In all cases, the aspirated stops are seen raising the F0 at the initial parts of the pitch contours for all tones. Similarly, voiced stops lower the F0 of the initial parts of the pitch contour. Finally, the voiceless unaspirated stops also raise the initial F0, however, the rise is lower than the rise in case of voiceless aspirated stops.

To explore the effect of stop types on initial F0, we built an LME model with initial F0 as dependent variable, tone types (=4) and laryngeal contrast types (=3) as fixed factors and vowel, speaker, and gender as random factors. Using the *step()* function of the *lmerTest* package [29], we performed backward elimination of random and fixed effects of the LME model resulting in a reduced model with tone type and onset types as fixed factors, and vowel type as random factor. The LME model was subjected to a between laryngeal contrasts comparison of initial F0 value by tone types. Fractional degrees of freedom were computed using the Kenward-Roger method, with p-values adjusted using the Bonferroni method. The results of the comparison are tabulated in Table 2.

From Table 2 it can be summarized that the three laryngeal contrasts in Mizo have a distinct effect on the initial F0 of the following tone contour. The table also shows that initial F0 following a voiceless aspirated stop is the highest and following a voiced stop is the lowest.

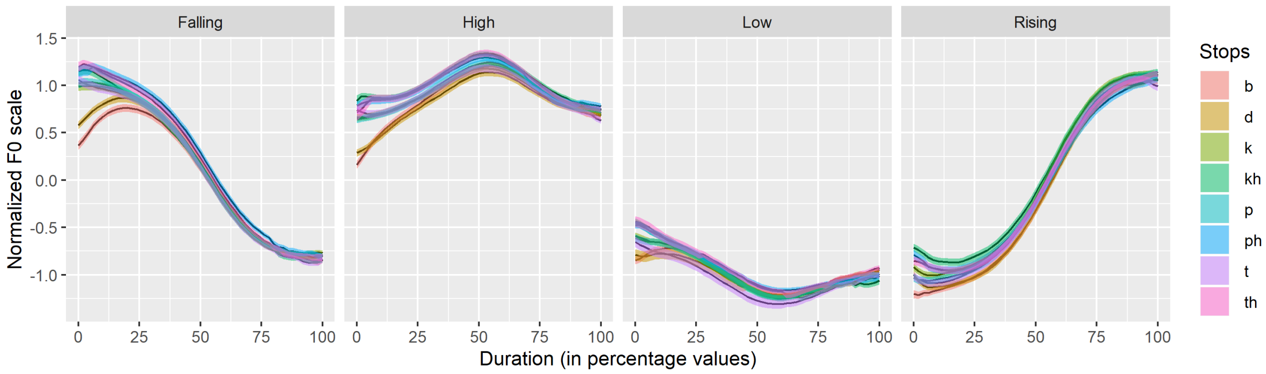

Figure 4: *Normalized F*0 *contours and standard errors of the four Mizo tones obtained from the 8 stops.*

Table 3: *Mean VOT and standard errors for Mizo stops.*

Stops	Falling	High	Rising	Low
/p/	14.5(0.7)	16.0(0.7)	14.8(0.8)	15.1(0.8)
/p^h/	83.1(4.0)	85.2(3.4)	92(3.4)	89.9(3.5)
/b/	−106.4(3.0)	−98.0(2.8)	−107.6(2.7)	−101.1(2.6)
/t/	16.6(0.6)	17.9(0.8)	17.9(0.9)	17.6(0.8)
/t^h/	84.4(3.9)	80.9(3.3)	89.6(3.5)	87.4(3.8)
/d/	−108.0(3.0)	−97.9(2.6)	−101.1(2.7)	−107.1(3.2)
/k/	32.1(1.1)	33.8(1.1)	36.3(1.3)	34.2(1.0)
/k^h/	102.1(3.9)	100.6(2.9)	108.5(3.7)	108.1(3.4)

Table 4: *Mean VOT of stops and standard errors in four tones by laryngeal contrasts.*

Voicing	Falling	High	Rising	Low
Voiced	−107.2(3.0)	−98.0(2.7)	−101.1(2.7)	−107.4(3.0)
Voiceless aspirated	89.8(3.9)	88.9(3.2)	96.7(3.5)	95.1(3.6)
Voiceless unaspirated	21.1(0.8)	22.6(0.8)	23.0(1.0)	22.3(0.9)

3.3. Effect of tone on VOT

The mean VOT and standard errors of eight Mizo stops categorized into three laryngeal contrasts, produced with the four Mizo tones, are presented in Table 3. While the effect of tones on VOT is not very apparent from Table 3 and Table 4, it can be safely concluded that at least in the case of voiceless aspirated stops, falling and high tones have shorter VOT. However, such consistency is not observed in case of other stop types.

To explore the effect of tones on VOT, we built an LME model with VOT as a dependent variable and laryngeal contrast types, tone, interaction of laryngeal contrasts x tones and POA as fixed factors. We considered vowel types, gender, and speaker as a random variable. The LME model was subjected to a backward elimination of random and fixed effects by using the *step()* function of the *lmerTest* package [29]. A reduced model emerged with laryngeal contrast type, tone, and POA as fixed factors, and vowel type and speaker as random factors. Subjecting the reduced model to a type II Wald chi-square test revealed a significant effect of tone on VOT [$\chi^2(3, N = 4789) = 26.6, p < 0.001$]. At the same time, the interaction of laryngeal contrasts x tones also showed significant effect on VOT [$\chi^2(6, N = 4789) = 56.5, p < 0.001$] confirming the effect of tones on VOT. The LME model was subjected to a between tone types comparison of VOT and adjusted for laryngeal contrast types and POA. Degrees of freedom was computed using the Kenward-Roger method, with p-values adjusted using the Bonferroni method. The results of the comparison are tabulated in Table 5. As seen in Table 5, in terms of VOT, in the context of a falling tone, VOT significantly decreases. When we compared VOT by each onset stop, again we noticed that the falling tones are significantly shorter than the rising tones in all onset conditions.

Table 5: *Result of the pairwise comparison of VOT.*

Contrast	Estimate	SE	df	*t* ratio	*p* value
Falling - High	-3.29	0.963	4787	-3.420	0.0038
Falling - Low	-1.68	0.963	4787	-1.748	0.4832
Falling - Rising	-4.99	0.962	4787	-5.181	<.0001
High - Low	1.61	0.964	4787	1.669	0.5709
High - Rising	-1.69	0.963	4787	-1.759	0.4715
Low - Rising	-3.30	0.963	4787	-3.428	0.0037

4. Discussion and conclusion

The results of this study confirm that as in the case of non-tone languages, Mizo, a tone language, also shows evidence of consonantal perturbation on the following F0 contour. There is clear evidence of CF0 in Mizo, in all tones as demonstrated in the sections above. The three-way laryngeal contrast in the onset stops of Mizo also induce three distinct patterns of effect on the initial F0 contour of Mizo tones. However, this study did not investigate the extent of the effect into the F0 contour.

Mizo also shows the indication of tonal effects on VOT. Again, the effect is more prominent in the aspirated stops. In the case of aspirated stops, the following falling and high tones induce VOT shortening. It was evident from the statistical measurements that rising tone is associated with the longest VOT, whereas falling tones are associated with the shortest. In other words, tones that begin at a high F0, such as the falling or high tones in Mizo, result in shorter VOT. On the other hand, rising tones, that begin from a lower F0 range are associated with longer VOT. Similar inverse relationship between F0 height and VOT duration is also observed in non-tone languages such as English and Korean and in tone languages such as, Mandarin Chinese and Cantonese [12]. This may be due to the slowing down of the vocal folds vibration during the production of a rising tone because of the increase in the vocal folds tension. As in the case of vowel effects on Mizo tone contours, reported in an earlier study [31], the laryngeal contrast effects are also limited to the initial 25% of the F0 contour. In case of Mizo, the initial 25% of the F0 contour exhibits significant coarticulatory effects. During this time speakers adjust their vocal cords to reduce IF0 and CF0 and induce tone specific F0 features.

5. References

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