Tone and voicing in Cao Bằng Tai

Implications for tonal evolution and change

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This study examines the phonetic realization of tones and onsets in Cao Bằng Tai. Previous studies of this language indicate that historically voiced plosives remain redundantly cued by closure voicing and/or breathy voice. Our age- and gender-stratified sample of 19 speakers reveals a linguistically homogeneous speech community in which historically voiced plosives are realized as voiceless and lightly aspirated, potentially merging with the aspirated plosive series. Our data show no intrinsic covariation of pitch in syllables with historically voiced onsets, but syllables with historically voiceless aspirated onsets show significantly increased pitch compared to unaspirated onsets. These findings suggest that while historical sonorant devoicing may well have conditioned the initial split, the phonetic precursors involved in the onset merger implicate raising, rather than lowering, of pitch. Our study of Cao Bằng Tai thus provides new insights into the internal chronology of tonogenetic processes in Tai languages.

Keywords: tonogenesis, tone, phonation, register split, sound change, Tai languages, acoustics

1. Introduction

1.1 Tonogenesis and tonal register split

Tonal register split is a bi- or tri-partitioning of an existing 2 or 3-tone system based on laryngeal properties of initial consonants. A classic example of a tonal register split is illustrated by the case of Cantonese (Table 1). According to the model of Haudricourt (1954, 1961, 1965), Middle Chinese can be reconstructed with three tones derived from laryngeal events arising from the co-production of historical coda consonants. On Haudricourt's model, subsequent devoicing of the historically voiced onsets was responsible for the tonal register split in systems such as Cantonese.

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Table 1. Tonogenesis and tonal register split in Cantonese. After Haudricourt (1961: 165)

Initials	**Finals**		
	Open/nasal	**Glottal**	**Spirant**
p, p^h, t, t^h, k, k^h	high falling	high rising	high level
(b>) p~p^h, (d>) t~t^h, (k>) k~k^h, m, n, l	low falling	low rising	low level

In many languages, it is not only obstruents, but also sonorants that are implicated in tonal register split. Based on data from some Vietic and Tai languages, Haudricourt (1961) also proposed that the first step in the two-way split of tonal systems was triggered by the loss of aspiration in the (historically voiceless, pre-aspirated) sonorants. His evidence for this proposal came from Cao Bằng Tai (which he called Tho), shown in Table 2. Because Cao Bằng Tai still apparently retained a distinct onset series derived from historical voiced obstruents, illustrated here by 'fat', Haudricourt surmised that the loss of aspiration in the sonorant subseries – that is, the merger of the voiced and voiceless sonorants – must have been the essential first step in the process of tonal register split.[1]

Table 2. Correspondences between "Tho" and "Tho of Cao Bang" (Cao Bằng Tai). After Haudricourt (1961: 167)

Example	**Common Tai**	**Tho**	**Tho of Cao Bang**
'dog'	*^{h}ma	mā	mā
'year'	*pi	pī	pī
'to come'	*ma	mà	mà
'fatty'	*bi	pì	βì

Haudricourt's observation was picked up on by Matisoff (1973), Chen (1992), and L-Thongkum (1997) and subsequently extended by Pittayaporn (2009) to explain the diachrony of tone splits in Tai more generally (Figure 1). In Pittayaporn's model (2009: 247–8), the Proto-Tai tonal categories were originally influenced by the phonation type of the onsets, creating distinct realizations of tones after voiced and voiceless onsets (Stage I). Subsequently, these phonetic differences became phonologized into two categorical but redundant pitch registers (Stage II). This redundancy permitted the merger of the voiced and voiceless sonorants, resulting in two phonemic pitch registers (Stage III). Consequently, a

1. "Ce qui semble essentiel dans tous ces dialectes pour obtenir la bipartition du système tonal, c'est la perte de l'aspiration des sonnantes" (Haudricourt 1961: 166).

binary register split occurred, doubling the number of tones. Cao Bằng and other conservative dialects are argued to have only completed this third step, while most other Tai dialects have gone on to completely devoice the original voiced obstruents, which surface as either plain voiceless or aspirated consonants.

Stage I	*^{h}n-	*t-	*A,	*B,	*C,	*D	phonetic effect of phonation type on tonal realization
	*n-	*d-					
Stage II	*^{h}n-	*t-	*A1,	*B1,	*C1,	*D1	categorical but redundant pitch registers
	*n-	*d-	*A2,	*B2,	*C2,	*D2	
Stage III	*n-	*t-	*A1,	*B1,	*C1,	*D1	phonemic registers in sonorants
		*d-	*A2,	*B2,	*C2,	*D2	
Stage IV	*n-	*t-	*A1,	*B1,	*C1,	*D1	pitch registers not predictable from onsets
			*A2,	*B2,	*C2,	*D2	

Figure 1. Schematic representation of the stages of tonal register split after Pittayaporn (2009: 248)

Pittayaporn (2009: 247–248) is explicit in proposing that a single voicing-based pitch register split event occurred for both sonorants *and* obstruents. He hypothesized that when the split happened in the sonorant subsystem, it happened everywhere, even though voicing would still have been redundantly signaled in the obstruent subsystem. In other words, the phonologization of the intrinsic pitch differences is assumed to precede any mergers in the laryngeal system, but subsequently, the sonorant merger preceded the obstruent merger (see also L-Thongkum 1997: 215). Aspiration-based splits among the obstruent series are assumed to be later developments, occurring after the initial binary tonal register split.

However, the claim that the loss of aspiration in the voiceless sonorants constitutes the critical first step in a sequence of sound changes leading to phonemic tonal register splits seems somewhat paradoxical given our understanding of tonal developments in Tai languages (cf. Gedney 1972; Chamberlain 1975; Li 1977: 43–53). First, only a relatively small subset of Tai languages, such as Central

Thai and Saek, show tone splits based on aspiration, but all show splits based on voicing. Second, when the aspiration-based splits are observed, they are often limited to only a subset of the three historical tonal categories, usually the *A tone, in contrast to the voicing-based bifurcation in the obstruents, which affected all historical tonal categories.[2] In other words, if the merger of the historically voiceless aspirated sonorants with their plain voiced counterparts set off the tonal register split, it remains unclear why splits based on voicing are significantly more common than splits based on aspiration.

An additional issue arises when we consider the phonetic precursors which led to the formation of categorical pitch registers. For onset mergers to lead to tone split, the phonetic effects of onset phonation type on the following pitch contours first need to be phonologized. But what, exactly, is the nature of these effects? One possible candidate is the frequently cited correlation between obstruent voicing and lower pitch. There are good phonetic reasons to expect lower pitch (and potentially breathy phonation) to accompany the production of voiced obstruents, the result of gestures taken to overcome the conflicting requirements of obstruency and voicing (Ohala 1975; Hombert et al. 1979; Hombert 1978; Westbury 1983; Ohala 2011). However, it is not at all obvious that pitch lowering is predicted to accompany the production of voiced sonorants, which do not pose any particular impediments to sustaining vocal fold vibration during oral closure (Ohala 1975; Hombert et al. 1979). If tone splits are initiated by the phonologization of co-intrinsic phonetic effects in the sonorant subsystem, if anything, this should imply pitch raising following voiceless sonorants (Dantsuji 1984; Maddieson 1984; Kirby 2022). But if we assume a single voicing-based pitch register split event for both the sonorant and obstruent subsystems, this leaves us without a shared phonetic precursor to explain the invariable patterning of voiced sonorants with voiced obstruents in the subsequent phase of the tone split.

To better model how obstruent and sonorant devoicing processes interact in tone splits, it would be helpful to have a clearer understanding of how their phonetic realizations — especially their effects on the pitch of the following segments — change over time. This makes conservative dialects such as Cao Bằng Tai, which retains a voicing contrast in the obstruent subsystem, of critical importance for our understanding of how the process of tone splitting unfolds, since most other Tai languages have long since merged the historically voiced obstruent onsets with other onset series.

2. For example, in the Central Thai dialect spoken in Suphanburi there was an aspiration-based split in the *A category (A1-23-4) but not in the *B or *C categories (B123-4, C123-4).

1.2 Previous studies of Cao Bằng Tai

As described by Hoàng Văn Ma (1997), a native speaker of a variety spoken at Trùng Khánh in Cao Bằng province, as well as Pittayaporn (2009: 246–247) and Pittayaporn and Kirby (2017), Cao Bằng Tai (hereafter CBT) has a system of six lexical tones on sonorant-final ("smooth") syllables. While both Hoàng Văn Ma and Pittayaporn and Kirby denote the tones using slightly different numbering systems, here we label the tones using Gedney's (1972) "tonebox" notation (Table 3). In this system, A, B, C, and D indicate the Proto-Tai tonal categories,[3] and numbers 1–4 refer to historical classes of initial consonants, namely voiceless aspirated, voiceless unaspirated, implosive,[4] and plain voiced stops, respectively. Here and in the remainder of the paper, we use bilabials (*b, *m, etc.) to represent all places of articulation for a given manner, so that *m represents {*m *n *ɲ *ŋ *l}, *b represents {*b *d}, etc.

Table 3. Gedney tone box illustrating consonant-tone co-occurrence restrictions in Cao Bằng Tai (after Pittayaporn and Kirby 2017: 71)

	*A (*píng*)	*B (*qù*)	*C (*shǎng*)
*pʰ, *ʰm (>m)*			
*p	A123	B123	C123
*ɓ (>b)			
*b (>b̤), *m, *v	A4	B4	C4

Both Hoàng Văn Ma (1997) and Pittayaporn and Kirby (2017) describe CBT as distinguishing 31 initial consonants, among them four series of obstruents: plain /p t c k/, aspirated /pʰ tʰ kʰ/, voiced /b d/ (historically implosive *ɓ *ɗ) and breathy voiced /b̤ d̤/ (historically modal voiced *b *d),[5] along with voiced /v z ɣ/ and voiceless fricatives /f ɬ s x h/ and sonorants /m n ɲ ŋ l/. While the plosives are results of diachronic shifts that turned the historical implosives into plain voiced plosives, and the historical plain voiced plosives into breathy voiced plosives, the

3. These correspond to Sinitic *píng (A), qù (B), shǎng (C),* and *rù (D)* tones, respectively. Note that in the Sinitic tradition, B corresponds to *shǎng* and C to *qù;* see Court (1998).

4. Li (1977: 68–71, 107–111) and Gedney (1972) refer to this class as pre-glottalized but Pittayaporn (2009: 72, 105–107) reconstructs it as implosive.

5. Note that what we transcribe as plain and breathy stops, Hoàng Văn Ma (1997) transcribes as pre-glottalized and plain voiced stops, respectively. Here and in the remainder of the paper, we use bilabials (*b, *m, etc.) to represent all places of articulation for a given manner, so that *m represents {*m *n *ɲ *ŋ *l}, *b represents {*b *d}, etc.

sonorants resulted from neutralizations of the historical plain voiced (*m) and pre-aspirated voiceless (*ʰm) sonorants.

Table 3 also highlights the co-occurrence restrictions that hold between onsets and tones in CBT. Voiceless aspirated (/pʰ/), voiceless unaspirated (/p/), and modal voiced (/b/) plosives, as well as voiceless fricatives (/f/), always co-occur with one of three high-register tones, whereas the breathy voiced (/b̤/) plosives and the voiced fricatives (/v/) always co-occur with one of the three low register tones. Syllables beginning with sonorant onsets (/m/) can occur with any of the six tones, owing to the merger between the historically voiced and voiceless aspirated sonorants.

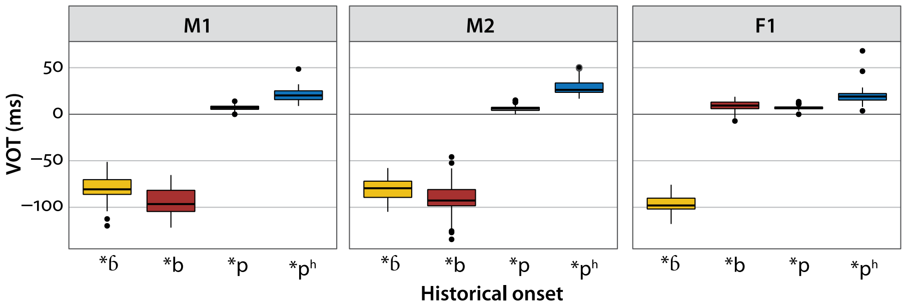

Figure 2. Voice Onset Times (VOT) of plosives in the three CBT speakers, based on data from Pittayaporn and Kirby (2017). Note that *ɓ > [b], while *b > [b̤] (for M1 and M2) or [p] (for F1)

It has been repeatedly proposed that breathy voicing first emerges as a redundant phonetic cue to onset voicing, and that it is this difference in voice quality, rather than onset voicing itself, which conditions pitch lowering (Haudricourt 1954; Pulleyblank 1978; Ferlus 1979; Thurgood 2002). Pittayaporn and Kirby (2017) made acoustic analyses of recordings from one female and two male speakers of the Trùng Khánh variety of CBT. While the two male speakers realized the historically voiced plosives *b as (breathy) voiced /b̤/, they were consistently devoiced in the speech of the younger female speaker (Figure 2).

These findings suggest that the historically voiced stops may have developed differently in the speech of different CBT speakers. For speakers M1 (aged 75 in 2010) and M2 (aged 50), *b was realized as a breathy voiced plosive /b̤/, although more robustly for speaker M1 than M2, for whom tokens of *b and *ɓ could not always be distinguished in terms of voice quality (Pittayaporn & Kirby 2017: 76–78). For speaker F1 (aged 57), *b was consistently realized as a voiceless unaspirated (short-lag) plosive, something potentially intermediate between

/p/ and /pʰ/. Table 4 illustrates the synchronic realizations of the historical onset classes for the three speakers.

On this basis, Pittayaporn and Kirby (2017) suggested that closure voicing and breathiness might covary: as pre-voicing waned, breathiness came to take on a more prominent role. Whether *b > /b̤/ would ultimately merge with *ɓ > /b/ (as seemed to be the case for speaker M2) or with *p > /p/ or *pʰ > /pʰ/ (as seemed to be the case for speaker F1) would determine how the tone split would ultimately resolve. However, with data from only three speakers, we could do little more than speculate.

Table 4. Synchronic realizations of the historical onset classes for the three speakers, based on data from Pittayaporn and Kirby (2017)

PT onset	Gedney row	M1	M2	F1
*ʰm	1	m	m	m
*pʰ	1	pʰ	pʰ	pʰ
*p	2	p	p	p
*ɓ	3	b	b	b
*b	4	b̤	b̤ ~ b	p ~ pʰ
*m	4	m	m	m

1.3 The present study

We therefore returned to Cao Bằng in 2015 to gather a larger, more diverse data sample, with the aim of studying change in progress using an apparent-time paradigm. We worked with a speech community based in Khuổi Ky, a hamlet about 20 kilometers east of our previous field site of Trùng Khánh district center, but less than two kilometers away from the Sino-Vietnamese border (Figure 3).

Based on our previous findings, we expected the reflex of *b might still be pre-voiced in the speech of older male speakers, but to be realized as primarily breathy voiced (but potentially without consistent voice lead) in the speech of younger female speakers. We thus hypothesized that age and sex would be good predictors of whether pre-voicing or breathiness would be the main phonetic exponent of *b. Unlike in our previous study, here we also looked for evidence of *co-intrinsic pitch perturbations* (CF0): microprosodic effects of onset consonants on the pitch of the following vowels. CF0 is typically higher following phonologically voiceless (fortis) obstruents (Meyer 1897; House & Fairbanks 1953; Hanson 2009; Ting et al. 2025) and sonorants (Maddieson 1984; Kirby 2022), compared with the voiced/lenis member. Lowered F0 is also frequently observed to accom-

Figure 3. Top: Locations of Cao Bằng province (red) and Trùng Khánh district (black) in Vietnam. Bottom: Locations of Trùng Khánh town (*thị trấn huyện ly*) and Khuổi Ky hamlet within Trùng Khánh district. Maps by the authors using Global Administrative Areas (GADM) shapefiles (version 2.7, accessed 22 March 2024)

pany breathy onsets (Kagaya & Hirose 1975; Shimizu 1994; Dutta 2007; Berkson 2019; Dmitrieva & Dutta 2019; Schertz & Khan 2020) and breathy vowels more generally (Klatt & Klatt 1990; Gordon & Ladefoged 2001; Esposito & Khan 2020). CF0 is thus an additional useful acoustic correlate to consider, especially in languages like CBT where VOT differences may not necessarily clearly distinguish all onset types. In particular, for speakers who realize *b with breathy voicing, we might expect to see a CF0 profile which is more similar to that of /b/ (<*ɓ), even if there is no evidence of closure voicing in the reflex of *b whatsoever. Similarly, differences in CF0 should help us to distinguish instances of 'true p^h' (<*p^h), which would be expected to show higher CF0, from 'breathy p^h' (<*b), which would not.

Contrary to our expectation, our findings indicate that the original voiced stops in Khuổi Ky have been completely devoiced in all speakers: the phonetic realization of *b is something like /p/ or /p^h/, similar to speaker F1 in our Trùng Khánh data. However, our careful attention to microprosodic effects led us to discover that this CBT variety exhibits seven tonal categories including three distinct variants of the historical A tone but shows no mergers of tones across historical tone categories. Together, these findings have implications for our understanding of the chronology of tonal register split.

2. Methods and materials

For brevity and clarity, we provide only the essential details of our methods and materials here. Further details are available in the Supplementary Materials.[6]

2.1 Speakers

Nineteen native speakers of CBT (10 female, ages 20–65, median 41; 9 male, ages 27–75, median 46) were recorded for the present study. All were born in Khuổi Ky or nearby villages. Out of the 11 participants who were married, all but one were married to another native CBT speaker. All participants spoke some Vietnamese, having had at least some schooling in this language medium. Impressionistically, Vietnamese proficiency was higher among the younger participants, but we did not attempt a formal assessment.

2.2 Materials

Participants were recorded producing 25 monosyllabic lexical items with the low vowel /a/, onsets in the set /b b̤ p p^h d d̤ t t^h l m v/, and tones appropriate for the onset class (see Appendix). Three repetitions of each item were recorded both in isolation, as well as in the carrier phrase /k^hɔj^{C1} p^huəj^{B1} ____ ɬaːm^{A1} pɤj^{B1}/ 'I say ____ three times'. This resulted in 150 tokens per speaker for a total of 2,850

6. https://osf.io/b82yh/

tokens. Seven tokens were excluded due to participant or experimenter error. In what follows, we focus on the subset of items with the onsets /b b̤ p pʰ l m v/.[7]

2.3 Recording procedure

Audio recordings were made using a head-mounted condenser microphone in the Khuổi Ky village hall. In addition to audio recordings, a simultaneous electroglottograph (EGG) signal was captured using a two-electrode, USB powered digital electroglottograph from Laryngograph, Ltd. (model EGG-D200). The EGG signal was used both to assist with segmentation of the audio signal as well as to compute the closed quotient (Cq), an estimate of the glottal duty cycle (Houben et al. 1992). A smaller Cq indicates greater glottal airflow and subsequently breathier voice (Marasek 1997). Further technical details are available in the Supplementary Materials.[8]

2.4 Acoustic measures

We focus here on seven acoustic measures: one temporal and six spectral. First, time from release of closure to onset of voicing (VOT) was measured for each obstruent; in the case of pre-voicing, this value is negative. We also extracted six spectral features at 5 ms intervals over the syllable rime (so including a sonorant coda, if present). In addition to the fundamental frequency (F0), we measured the (corrected) differences in the harmonic amplitude measures H1*-H2*, H1*-A1*, H1*-A2* and H1*-A3*, and the cepstral peak prominence (CPP), a measure of how far the cepstral peak emerges from the cepstrum background (Hillenbrand & Houde 1996). The first four spectral balance measures were successful at distinguishing reflexes of *b from other onset types in our previous study of Cao Bằng Tai (Pittayaporn & Kirby 2017). We include CPP here as it is not reliant on a trackable F0, unlike the spectral tilt measures. For an overview of these and other acoustic correlates of voice quality, see Garellek (2019) or Esposito and Khan (2020).

7. Because of an accidental gap in the CBT lexicon, there is one item in the sonorant series, /laːŋ^{B2}/ 'barn', which begins with /l/ instead of /m/, there being no smooth /m/-initial syllables with tone B2. For simplicity, in what follows we treat this item as if it has an /m/ onset.

8. https://osf.io/b82yh/

2.5 Predictions

Based on previous findings, we formulated three predictions before making our recordings.

P1: The historically voiced plosive *b would be canonically realized with voicing lead/negative VOT in the speech of more conservative speakers (who we anticipated to be older and male).
P2: The historically voiced plosive *b would be canonically realized with voicing lag/positive VOT in the speech of more innovative speakers (who we anticipated to be younger and female).
P3: Finally, we predicted that breathiness would be the least pronounced in the speech of more conservative speakers (who would also have the most voice lead), manifested through lower spectral balance measures, higher pitch (F0), and higher Cq, and most pronounced in the speech of the most innovative speakers (with the least voice lead), manifested through higher spectral balance measures, lower F0, and lower Cq.

3. Results

In the following, we present visual data summaries and descriptive statistics, focusing on group-level effects and empirical estimates. Note that while all time-varying acoustic measures, such as F0, were speaker-normalized into *z*-scores prior to statistical analysis, we transform them back into (normalized) intuitive scales for plotting. Additional details can be found in the Supplementary Materials.[9]

3.1 Voice onset time

As seen in Figure 4, predictions P1 and P2 were not borne out: we observed virtually no variability in the realization of *b in our speaker sample. Rather, all Khuổi Ky speakers consistently devoiced the historically voiced PT plosive *b. Similar to what was found for Speaker F1 by Pittayaporn and Kirby (2017), the VOTs for *b for this speaker sample were all short-lag, with the means falling in-between those of *p and *p^h. Statistical comparisons find significant differences in VOT for female speakers between *b ~ *p (*est.* = 9 msec) and *p ~ *p^h (12 msec, both $p < 0.001$) but no significant difference between *b and *p^h (*est.* = 3 msec,

9. https://osf.io/b82yh/

$p = 0.18$). For male speakers, differences between lag times are significant for *b ~ *p (*est.* = 10 msec), *b ~ *p^h (*est.* = 9 msec) and *p ~ *p^h (*est.* = 20 msec, all $p < 0.001$). There was no significant effect of speaker age.

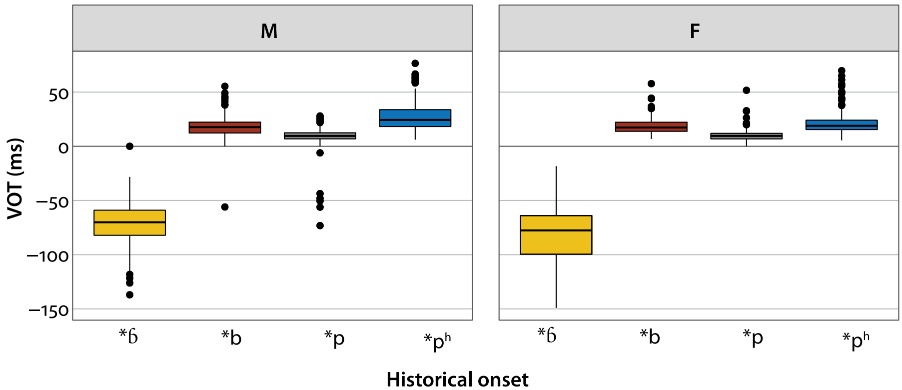

Figure 4. VOTs of the four historical plosive classes grouped by speaker sex (based on nine male and 10 female speakers)

3.2 Voice quality measures and EGG closed quotient

Figure 5 shows normalized spectral balance measures of the seven historical onset classes over the following vowel. As is evident from the plot, *p^h and *b differ from all other onset types in terms of both spectral balance measures as well as CPP and closed quotient for roughly the first quarter of the vowel, with estimated differences of up to 10 dB. Except for H1*-H2*, however, *p^h (>p^h) and *b (>p/p^h) are not distinguished by any of the measures. The pairs *ɓ (>b) and *m (>m), as well as *m (>m) and *v (>v) are never distinguished by any of the measures. While differences between other pairs are significant for some measures, it is clear that *b and *p^h have substantially different effects from the other onsets on the phonation type of the following vowels, likely the result of sharing similar degrees of post-release aspiration.

3.3 Historical laryngeal contrast and tone realization

Our expectation based on previous work was that, if CBT *b was being realized with breathy voicing, this might exert a measurable microprosodic effect on the F0 of the following vowel. Figure 6 shows the mean F0 trajectories following different onset types, plotted separately for each historical tone class. In all three contexts, F0 trajectories following the historically voiced onsets *b *m *v are all low,

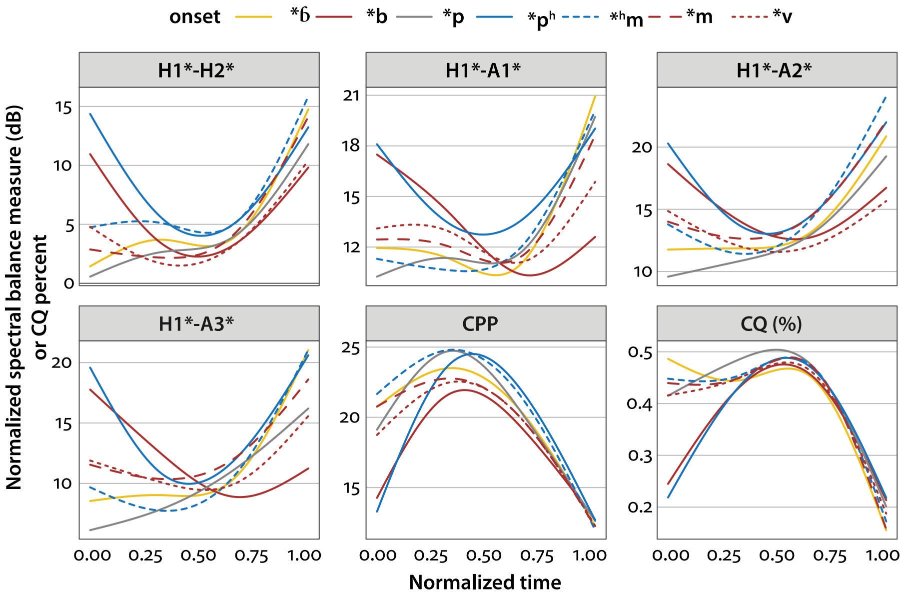

Figure 5. Mean empirical (normalized) spectral balance measures, CPP, and closed quotient by onset types. Time is normalized over the duration of the post-release vowel

reflecting the expected outcome of a voicing-based tone split in a Tai language, but there is no evidence of any residual perturbation of tones on syllables with *b which would suggest a synchronically breathy realization (i.e. tones on syllables with *b are not lower in pitch than those on syllables with *m or *v).

Unexpectedly, however, we found the tone trajectories following *^{h}m and *p^h to be realized with markedly *higher* F0 compared to tones following *p and *ɓ. This is most apparent for the A tones but can be seen to a lesser extent for the B tones as well. The difference between the aspirated and non-aspirated tones in the B column is modest, around 20 Hz, but statistically significant (see Supplementary Materials §2.4). The differences in the trajectories between *^{h}m/*p^h and *p/*ɓ observed in panel A (nearly 75 Hz at the 25% point) are far greater than what would typically be expected of a co-intrinsic F0 perturbation, of comparable magnitude to the differences between the high and low register reflexes of the historical C tone (around 60 Hz).

Struck by this finding, we plotted the data from the three Trùng Khánh speakers analyzed in Pittayaporn and Kirby (2017) in the same way (Figure 7). The patterns are not identical; in particular, the F0 trajectory following *p^h does not always pattern with that following *^{h}m. However, the tone on syllables headed by

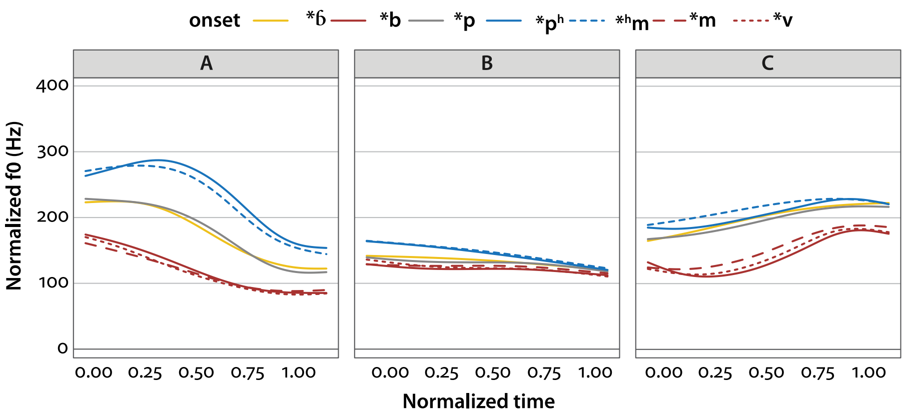

Figure 6. Average empirical (normalized) Fo trajectories of Khuổi Ky speakers by historical onset type and tone category

*ʰm does have a slightly higher variant, especially for the A tones of speakers M2 and F1.

4. Discussion

4.1 Summary

In contrast to our predictions (§2.5), our recordings of the Cao Bằng Tai variety spoken in Khuổi Ky revealed a relatively homogeneous speech community with neither age- or sex-stratified variation in realization of *b. However, we also discovered that the variety of CBT spoken at Khuổi Ky retains a conservative tone system, maintaining a three-way split in the A column (A1–23–4) and two-way splits in the B and C columns (B1–234 and C123–4), which differs from previous reports of a related variety (Hoàng Văn Ma 1997; Pittayaporn 2009; Pittayaporn & Kirby 2017). Unlike in many Tai languages, this variety shows no patterns of coalescence across historical tone categories, only mergers over different historical onset classes.

In terms of voice quality measures and VOT, *b and *pʰ could be regarded as merged, at least for the female Khuổi Ky speakers. The more salient difference between the genders is in the VOT of *pʰ, which is (slightly) more aspirated for male than female speakers. It is thus not possible to determine if the variation in VOT and voice quality we observed in Pittayaporn and Kirby (2017) represents stable variation, or evidence of change in progress. The system found at Khuổi Ky is most similar to the innovative female Trùng Khánh speaker (aged 57 in 2010)

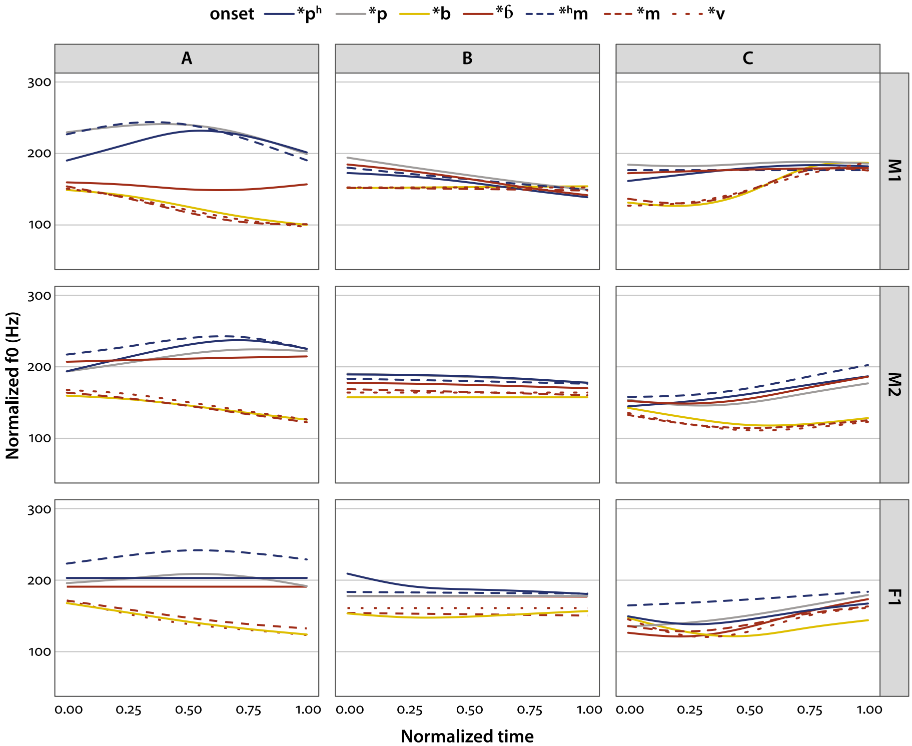

Figure 7. Average Fo trajectories of Trùng Khánh speakers by historical onset type and tone category, isolated syllables

in Pittayaporn and Kirby (2017), who had a completely devoiced realization of *b but still maintained it as a separate category distinct from *pʰ and *p via differences in voice quality. However, the fact that *b and *pʰ pattern together in terms of voice quality measures strongly suggests that Khuổi Ky is moving toward the neutralization of *b and *pʰ, independent of whether this represents an evolution from a previously Trùng Khánh-like state.

An unexpected finding of the present study was that both *ʰm and *pʰ still seem to co-occur with distinct reflexes of the A and B tones as compared to *p and *ɓ (§3.3). The Fo difference between the tones of *ʰm/*pʰ and *p/*ɓ syllables is even larger than the difference between the C tone reflexes following voiced and non-voiced segments, which previous authors have all analyzed as unambiguously distinct tones. For tone 2 (B1), the magnitude of this difference is rather less, around 20 Hz, but still statistically robust. Thus it seems reasonable to us to propose that the Khuổi Ky variety of CBT actually has seven phonetically distinct tonal categories, as shown in Table 5.[10]

Table 5. Revised Gedney tone box for the Khuổi Ky variety of Cao Bằng Tai

	A	B	C
$*p^h$, $*^hm$ (>m)	A1	B1	
*p	A23		C123
*ɓ (>b)		B234	
*b (>p/p^h), *m, *v	A4		C4

The variety of CBT spoken at Khuổi Ky seems to represent a Tai variety with a previously undocumented pattern of splits and mergers. The possible existence of a configuration of this type was mentioned by Li, but he also noted that "[s]uch a system is not represented in the material known to us" (1977: 47). The most similar varieties we have been able to identify are the Lao dialects of Roi-et and neighboring areas (Akharawatthanakun 2002), which also maintain a three-way split in the A column and two-way splits in the B and C columns, albeit with the opposite behavior of *p and *ɓ as found in Khuổi Ky (i.e., B123–4 and C1–234).

4.2 The origins of the Khuổi Ky tone system

As noted by both Haudricourt (1961) and Li (1977), the historical onset classes active in tone splits in Tai languages – aspirated obstruents ($*p^h$), aspirated sonorants ($*^hm$), plain obstruents (*p), glottalized obstruents (*ɓ), and voiced segments (*b *m *v) – tend to pattern together into maximally three different classes. Haudricourt (1961) primarily emphasized the behavior of aspirates ($*p^h$ and $*^hm$) versus glottalized obstruents (*ɓ) and voiced segments (*b *m *v), corresponding essentially to the "high/mid/low" division encoded in the Thai orthography. This three-way grouping of onsets, combined with the three original smooth syllable tones A B C, defines a system of nine possible tones. However, there are few or no languages which attest to such a system. The CBT system as described by Hoàng Văn Ma (1997) and Pittayaporn and Kirby (2017; also Table 3) appears to be a classic example of an outcome of the "Great Tone Split" (Brown 1975) where one set of tones developed following voiced segments, and a different set after non-voiced segments. But the data presented in §3 show a considerably more complex system, with a three-way split in the A tone and different patterning of the plain/glottalized series in the B and C tones.

10. The difference between this and previous analyses (Hoàng Văn Ma 1997; Pittayaporn 2009; Pittayaporn & Kirby 2017) may be due in part to whether the researchers were more attuned to differences in overall F0 height or F0 contour.

What is the most probable account of this system? Two general lines of explanation suggest themselves:

1. Pitch was raised following the aspirated series (*pʰ and *ʰm) and lowered following the voiced series (*b *m *v). In this scenario, *p and *ɓ remained neutral. This is essentially Haudricourt's proposal for the origin of the three-way split observed in many Tai varieties (Haudricourt 1972: 78–79).
2. An alternative account would be to propose that while all non-voiced segments exerted a raising effect on the pitch of the following vowel, the magnitude of the raising effect was greater for aspirates than for non-aspirates (plain and implosive obstruents). This also would have produced three sets of allotones, allowing for two different splits: one between voiced and non-voiced, and one between aspirated and non-aspirated, depending on the historical tone involved.

While the first account is widely accepted, it poses several issues from a phonetic perspective, as noted in §1. Arguably the most problematic is the fact that, although *m patterns with *b and *v, there is no phonetic basis to expect *m to lower pitch (Ohala 1975; Rischel 1986; Hanson 2009), and pitch is often not lowered following voiced obstruents in many languages either (Hanson 2009; Kirby & Ladd 2016; Kirby 2018; Kirby & Tan 2023; Pinget & Quené 2023; Ting et al. 2025). Although there have been proposals that sonorants of any phonation type can be freely produced with either high or low F0 (Kingston 2011), this leaves unexplained the fact that, at least in Tai languages, voiced sonorants *invariably* pattern with (historically) voiced obstruents in tone splits; what is variable is what subsequently becomes of the historically voiced obstruents, i.e. whether they "simply" devoice or also aspirate.

The second scenario seems to us to be on firmer phonetic ground. The phonetic basis for voiceless, especially (phonetically) voiceless aspirated segments, to raise pitch is well-established (Meyer 1897; House & Fairbanks 1953; Lehiste & Peterson 1961; Löfqvist et al. 1989; Hanson 2009), for sonorants as well as for obstruents (Dantsuji 1984; Maddieson 1984; Kirby 2022). In languages with just a two-way laryngeal contrast, whether /p/ acts as a "raiser" often depends on whether it is opposed to a truly pre-voiced [b], as in French or Dutch, or to a voiceless aspirated [pʰ], as in German or English. In languages with a three- or four-way contrast, the magnitude of the CF0 effect of /p/ can often be slightly less than that of /pʰ/ (Kirby 2018; Schertz & Khan 2020). Similarly, while implosives can also raise pitch, they often do so less vigorously than do voiceless obstruents (Painter 1978; Wright & Shryock 1993; Demolin 1995; Kirby 2022), potentially due to the antagonistic effects of simultaneous larynx lowering and contraction of the intrinsic laryngeal muscles (Cun 2009: 187 ff.). This is also consistent with the individual variation we observe in the present study (Supplementary Materials, §3.8). For example, in the A series, *p patterns with the aspirates for speaker F1 (as it does for speaker M1 from Trùng Khánh: Figure 7), but with the voiced series for speaker F2. There is also a great deal of individual variability in the B column. The observation that plain voiceless obstruents and implosives can, but need not, raise the pitch of the following vowel, together with the fact that voiced sonorants always seem to pattern together with voiced obstruents in tone splits, lead us to favor this second scenario.

Regardless of which line of explanation we pursue, an outstanding challenge is to explain why the magnitudes of the effects vary so much between the different historical tone classes. We do not have a satisfactory answer for this at present, but we will note that this pattern seems to reflect the frequent observation that the aspiration-based splits most often affect only the *A tone in Tai varieties (Gedney 1972: 200–201). There is also abundant evidence that the magnitude of micro-prosodic effects interacts with the local F0 environment (Silverman 1986; Chen 2011; Kirby 2018; Choi et al. 2020), which might explain why the effect is modulated by the historical tone class.

4.3 Implications for models of tonogenesis and tone split

Our initial motivation for investigating CBT was to shed further light on the evolution of tone splits. CBT is of special interest because it has merged historically voiced and voiceless aspirated sonorants, but not obstruents, suggesting that the merger of the sonorants preceded a merger of the obstruents in general. The variety of CBT spoken at Khuổi Ky provides a further snapshot of how complex the continued evolution of a tone system can be. It continues to evolve in a direction typical of many other Tai languages, as its historically voiced obstruents lose the last vestiges of their voicing and (probably) merge with the aspirated series, consistent with previous reports of them having been breathy voiced. At the same time, it has also begun the process of coalescence within, but not across, the historical tone categories. The fact that Trùng Khánh speaker M1 shows a similar three-way split in the A tones to the Khuổi Ky speakers as well as mergers in the B and C categories, while also maintaining phonetically distinct variants of the four historical voicing categories, indicates that the onset-based splits in one tone need not be complete before the system begins to evolve further.

If we adopt the second proposal for the origin of the CBT tone system, we can also reconcile the facts that aspiration-based splits are relatively rare while voicing-based splits are common with the proposal that the merger of voiced and voiceless aspirated sonorants is (at least in some cases) the first step in the evolution of tone splits: all non-voiced onsets (obstruents and sonorants) raised pitch relative to voiced onsets, but only in some cases was this raising greater for the aspirated than for the non-aspirated series. The apparent merger of B4 with B23, while admittedly rare, is documented for some Zhuang varieties (Li 1943; Liao 2016).

The variety of CBT spoken at Khuổi Ky suggests that the strong position taken by Pittayaporn (2009) that there first was a single voicing-based split conditioned by a sonorant merger, and only subsequently aspiration-based splits due to obstruent mergers, needs to be relaxed, at least in some cases. Khuổi Ky CBT strongly suggests that aspirated sonorants and obstruents ($*^{h}m$ and $*p^{h}$) can and perhaps often do pattern together during a tone split. If the first phase of the split involved phonologization of pitch differences between $*^{h}m$ $*p^{h}$ *p *ɓ on the one hand and *b *m *v on the other (Pittayaporn's Stage II), followed by merger of $*^{h}m$, *m > m (Stage III), we have no way to explain why *historical* $*^{h}m$ should subsequently pattern with $*p^{h}$ in conditioning a distinct allotone.

It is of course possible that some Tai languages followed a more classical pathway with an initial fundamental split based on voicing, followed by secondary splits based on aspiration (of sonorants as well as obstruents). However, at this point, it is not always possible to distinguish languages that first underwent splits based on aspiration from those that first underwent splits based on voicing. For example, in Khuổi Ky, it is logically possible that the first step in the tone split involved phonologization of lowered pitch following *b *m *v, followed by phonologization of raised pitch following $*^{h}m$ and $*p^{h}$, and only subsequently by a loss of aspiration in the voiceless sonorant series (but cf. §4.2). Hopefully, future phonetic studies of Tai dialects will provide data that can help us distinguish these possible chronologies.

5. Conclusion

This study has examined the phonetic variation in tones and onsets of Tai varieties spoken in Trùng Khánh district, Cao Bằng province, Vietnam. Although previous work led us to expect variation in the realization of historically voiced obstruents, our data from Khuổi Ky reveal a more homogeneous speech community where historically voiced obstruents have lost virtually all their distinct phonetic properties. At the same time, this variety maintains a conservative tone system, the structure of which suggests that the phonetic precursor of tone splitting involves different degrees of raising following non-voiced onsets. Cao Bằng Tai thus proves once again to be crucial for helping us to better understand the evolution of tone systems in Southeast Asia.

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Appendix. Word list

*Onset	Item	English gloss	Vietnamese prompt
*ɓ	baŋ^{A1}	'to run'	chạy
*ɓ	baː^{B1}	'to spill (liquid)'	đổ
*ɓ	baː^{C1}	'insane, crazy'	điên (khùng)
*b	b̤aːn^{A2}	'to crawl'	bò
*b	b̤aː^{B2}	'to kick'	quệt (chân)
*b	b̤aː^{C2}	'to lean on'	dựa vào
*^{h}m	maː^{A1}	'dog'	chó
*m	maː^{A2}	'to come'	đến
*^{h}m	maː^{B1}	'soak'	ngâm
*l	laːŋ^{B2}	'barn'	chuồng trâu
*^{h}m	maː^{C1}	'develop'	lớn lên
*m	maː^{C2}	'horse'	ngựa
*p	paː^{A1}	'to eat with hands'	bốc ăn
*p	paːŋ^{B1}	'thigh'	đùi
*p	paː^{C1}	'elder aunt'	bác gái
*p^{h}	p^{h}aː^{A1}	'turtle'	con rùa
*p^{h}	p^{h}aː^{B1}	'to split'	chẻ
*p^{h}	p^{h}aː^{C1}	'blanket'	chăn
*v	vaːŋ^{A2}	'rice stubble'	rạ
*v	vaːj^{B2}	'to sweat'	toát mồ hôi
*v	vaː^{C2}	'heaven'	trời
*t	tɔːŋ^{A1}	'big leaf for wrapping'	lá (chuối)
*t^{h}	t^{h}ɔːŋ^{A1}	'waterfall'	thác
*ɗ	dɔːŋ^{A1}	'related by marriage'	thông gia
*d	d̤ɔːŋ^{A2}	'copper, brass'	đồng

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