



Cues of voicing contrast in two Chinese dialects: Implication for sound change

Menghui Shi¹, Yiya Chen²

¹Fudan University, Institute of Modern Languages and Linguistics

²Leiden University Centre for Linguistics

shimenghui@fudan.edu.cn, yiya.chen@hum.leidenuniv.nl

Abstract

In the literature on tonogenesis, it is commonly believed that as onset voicing-induced fundamental frequency (f_0) differences are exaggerated, lexical tones would come into being, and the onset voicing distinction disappears. In some East and Southeast Asian tone languages, however, intermediate stages with tonal contrasts and voicing contrast co-existing have been reported. This study reports data from two Sinitic varieties (i.e., Shuangfeng Xiang and Lili Wu), which show the coexistence of the two types of laryngeal contrast, to shed light on what could be a possible diachronic pathway of changes in consonant voicing contrasts with lexical tones co-present in the system. Both varieties have obstruent voicing contrast and lexical tones; phonation serves to cue the voicing contrast. We found onsets from the voiced category consistently align with lower f_0 contours across dialects and generations. However, the relationship between laryngeal timing (in terms of voice onset time) and phonatory state (in terms of contact quotient of vocal folds) varies, which suggests different patterns of cue reweighting for the phonetic implementation of voicing contrast, possibly reflecting different stages of how the voicing contrast may maintain or disappear.

Index Terms: consonant-tone interaction, voicing contrast, cue reweighting, Chinese dialects

1. Introduction

Obstruent voicing contrast is known to differ along multiple phonetic dimensions across the world's languages. Differences not only exist in the relevant cues for voicing contrast [e.g., 1, 2] but also in how these cues are weighted [e.g., 3]. Cue reweighting can serve as a potential pathway for sound change. A notable instance involves the reweighting between the voice onset time (VOT) of an obstruent onset and the fundamental frequency (f_0) of its following vowel [4, 5]. This reweighting, often associated with tonogenesis in atonal languages acquiring lexical tones [6, 7], is realized with the exaggeration of onset-induced f_0 differences, leading to the emergence of lexical tones, while the onset voicing distinction disappears [8].

In some East and Southeast Asian tone languages, intermediate stages with co-existing tonal and voicing contrasts have been reported [e.g., 9, 10, 11]. The existence of such languages suggests that there may be additional stages between the rise of novel phonologized f_0 differences as tonal contrast and the fall of the original voicing contrast. It has been argued that, for these languages, the phonologization of an onset voicing contrast into a phonatory contrast can be a precursor to the development of f_0 distinctions on the following vowels [11, 12]. However, little has been done on the detailed developmental trajectory of cues and how these cue-reweighting processes manifest among different generations of

speakers of these languages, which calls for our current research.

In this study, we present data from two under-documented Chinese dialects (as shown in Figure 1), namely Shuangfeng Xiang Chinese (SF hereafter) and Lili Wu Chinese (LL hereafter), where coexisting voicing contrast and lexical tonal contrast have been reported [13, 14]. Additionally, phonation has been posited as an important cue for the voicing contrast in both dialects [15, 16]. The specific question we addressed in this study is how SF and LL maintain the co-existence of consonant voicing and lexical tone contrasts over time, answers to which would shed new light on a possible diachronic pathway of changes in tonal genetic processes in general.

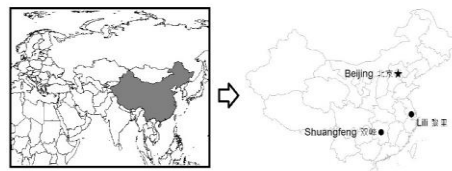


Figure 1: Map showing the location of Lili and Shuangfeng.

2. Tonal profiles in the two Chinese dialects

The laryngeal contrast of obstruents in Sinitic varieties displays either a two-way or a three-way distinction. The synchronic two-way systems are believed to have evolved from a three-way system in Middle Chinese (MC) through the devoicing of the voiced category [e.g., 17]. Wu and Old Xiang Chinese are recognized for predominantly maintaining three-way systems, which involve voiceless unaspirated, voiceless aspirated, and voiced distinctions, thereby preserving the voicing contrast, following Yuan [18]. The voiced obstruents in most of these dialects originated from the MC voiced category. In this study, we focused on the obstruent voicing contrast, namely the laryngeal distinction between voiceless unaspirated and voiced obstruent onsets, with a plan to further investigate the contrasts involving the voiceless aspirated counterparts.

2.1. Lexical tones

SF is a representative variety of Old Xiang, while LL is commonly classified as a member of the Tai Lake subgroup of the Northern Wu dialect group [19]. Figure 2 depicts the f_0 contours of the lexical tones in both dialects. SF exhibits five lexical tones: Two level tones (T1 and T5), two rising tones (T2 and T4), and one falling tone (T3). T1, T3, and T4 start in a higher f_0 range (above 180 Hz, high-register), while T2 and T5 both start in a lower f_0 range (under 180 Hz, low-register).

In LL, there are eight lexical tones. Tones marked with odd numbers initiate within a higher f_0 range (above 160 Hz, high-register), while those marked with even numbers initiate within a lower range (under 160 Hz, low-register). Notably, both T7

(black dash-dotted) and T8 (dark grey dash-dotted) are associated with syllables having a glottal coda /ʔ/ and showing much shorter duration than other tone-bearing syllables.

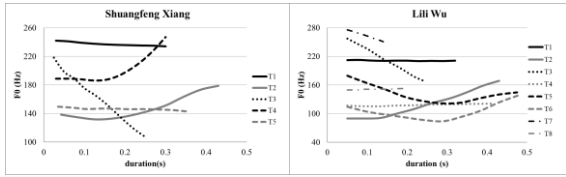


Figure 2: f_0 contours of the lexical tones in SF (female; born in 1953) and LL (male; born in 1948).

2.2. Co-occurrence constraints on laryngeal onset, lexical tone, register, and phonation

As shown in Table 1, both dialects exhibit complex co-occurrence patterns on laryngeal onset, lexical tone, register,

Table 1: Co-occurrence constraints on laryngeal onset, lexical tone, register, and phonation in SF and LL.

Laryngeal onset	SF (Shuangfeng Xiang)	LL (Lili Wu)	Register	Phonation
voiceless unaspirated	T1-55, T2-13, T3-41, T4-22	T1-44, T3-53, T5-423, T7-5	high	modal
voiced	T2-13, T5-22	T2-13, T4-22, T6-213, T8-3	low	breathy

3. Methodology

3.1. Stimuli

To investigate the realization of onset voicing contrasts across dialects and generations, we constructed stimulus lists for both dialects which comprise a near-minimal set of monosyllabic words carrying lexical tones involving all potential obstruent voicing contrasts. In SF, the onset constraints of the two level tones (i.e., T1 and T5) are in complementary distribution. With the voicing contrast in T2, there are 2 pairs of onset voicing contrast in SF. In LL, the co-occurrence constraints on obstruent onsets for high-register and low-register tones are in complementary distribution originating from MC tonal categories, forming 4 pairs of onset voicing contrast accordingly.

All pairs of target words begin with an alveolar (/t d/) plosive. We included 2 vowels (/i ə/) for SF and 3 (/a ε i/) for LL. Previous studies have shown that word frequency or familiarity may affect the phonetic realizations of lexical tones [e.g., 22]. An educated native speaker who also participated in the experiment confirmed that all stimuli are frequent and familiar words in each dialect.

3.2. Participants and procedure

As it is hard to investigate sound changes in real time [23], we adopted the approach of studying variations across different age groups in apparent time. To this end, we elicited data from speakers of two generations (old vs. young). 37 native speakers of SF and 20 native speakers of LL participated in the experiment. In SF, 22 belong to the older generation (9 males and 13 females born between 1950 and 1968, $M = 58$ years, $SD = 6$ years), and 15 to the younger generation (7 males and 8 females born between 1975 and 1990, $M = 35$ years, $SD = 6$ years). In LL, there were 10 participants for each generation: 5 females and 5 males born between 1939 and 1957 for the older generation ($M = 67$ years, $SD = 6$ years), and 5 females and 5 males born between 1981 and 1994 for the younger generation ($M = 29$ years, $SD = 4$ years).

The recordings were conducted in a quiet room for all participants. Stimuli were presented twice as differently randomized lists via the Field Phon program [24]. The

and phonation. The tone values here are transcribed following Chao’s tonal transcription system [20], where 5 indicates the highest end of a speaker’s pitch range into levels and 1 the lowest. In general, syllables with voiceless unaspirated onsets tend to co-occur with high-register tones, while those with voiced onsets typically associate with low-register ones. It is worth noting that T2 in SF is an exception as there is no strict co-occurrence constraint. The association of T2 with voiceless unaspirated onsets resulted from a historical change wherein syllables with a stop coda lost their coda, and their contours merged with those of T2 associated with voiced onsets [13].

In addition, phonation has been argued to serve as a cue for the voicing contrast in surrounding dialects [15, 21]. Their phonation realized over the first half of the following vowels has been shown to vary from clearly modal (voiceless unaspirated) to breathy (voiced), although there are variations across dialects and speakers.

participants first heard a prerecorded question in SF/LL, read by a native speaker, and then answered the question verbally with the target words on the screen. The pre-recorded question was “What is it called in SF/LL?” The participants were asked to pronounce each word at their normal speaking rate. Acoustic recordings and simultaneous electroglottographic signals (EGG) were recorded via Laryngograph microprocessor EGG-D800 with a Sennheiser PC 151 Headset condenser microphone connected to a laptop computer. In total, 592 tokens (8 stimuli \times 2 repetitions \times 37 participants) for SF and 960 tokens (24 stimuli \times 2 repetitions \times 20 participants) for LL were collected.

3.3. Analyses

Segments were manually identified using Praat [25], primarily based on the periodicity in the acoustic waveform and complemented by spectrographic analyses. Three sets of parameters were measured: Voice onset time (VOT), fundamental frequency (f_0) contours, and laryngeal contact quotient (CQ) via VoiceSauce [26] and EGGWorks [27].

Firstly, raw VOT values for all onsets were measured. Negative VOT was defined as the presence of voicing lead throughout much or all of the closure and was measured from the onset of voicing during plosive closure to closure release. In this study, any token with closure voicing, whether full or partial, was treated as having lead VOTs. Secondly, f_0 in Hz was automatically measured at twenty equidistant points over syllables, starting from the first regular vocal pulse to the end of the syllable. Raw f_0 values at all points were further normalized using within-speaker z -scores. Thirdly, CQ, defined as the proportion of vocal fold contact area during every single vibratory cycle value, was chosen as a reflection of phonatory conditions. In general, higher conductance corresponds to greater vocal fold contact, while lower conductance corresponds to lesser contact. CQ values were measured over the one-third, middle, and two-third points of the vowel using the Hybrid method, given its widespread adoption in studies of tone languages [e.g., 28, 29].

Three types of multilevel regression models were evaluated, namely linear mixed-effects models (LMMs) for VOT and CQ, generalized linear mixed-effects models (GLMMs) for the devoicing change of voiced onsets, and growth curve analysis (GCA) for f_0 contours. For statistical modeling of each

dependent variable (i.e., VOT, f_0 , and CQ), we included the main effects of three independent variables: Onset (unaspirated vs. aspirated vs. voiced), Tone (SF: T2 vs. T1&T5; LL: T1&T2 vs. T3&T4 vs. T5&T6 vs. T7&T8), Generation (old vs. young), and their interactions. For CQ, Position (one-third vs. middle vs. two-thirds) was added as an independent variable. A bottom-up procedure of modeling was consistently conducted. Three control variables (i.e., Vowel, Gender, and Repetition) were further tested in a stepwise fashion via model comparisons to determine which of them should be considered in the final model. Speaker by independent variables and Item were also tested as random structures. *** indicates $p < 0.001$ and * $p < 0.05$.

4. Results

4.1. VOT

Figure 3 shows raw VOT distributions with density curves in both dialects as a function of the onset voicing contrast. The two dialects exhibited significant differences. In SF, the factor Onset significantly improved the model fit [$\chi^2=349.1^{***}$]. /t/ was realized with a short voicing lag, whereas /d/ had either a positive short voicing lag or a negative voicing lead. These VOT patterns were generally consistent across lexical tones. However, the distributional density of voicing lead in the old generation was more concentrated than in the young generation, indicating that older speakers produced more VOT lead tokens [$\chi^2=14.2^{***}$]. GLMMs were further run to quantify the effects of speaker generation via a new dependent variable labeled ‘VOT-index’ with binary codes (‘0’: VOT lead vs. ‘1’: VOT lag). Results confirmed that /d/ produced by younger speakers devoiced more than older speakers [$t=12.6^{***}$]. Contrary to SF, in LL, /t/ and /d/ were consistently realized as short voicing lag with a mean concentrated around 10 ms and largely overlapped in both generations. All variables failed to show a significant effect.

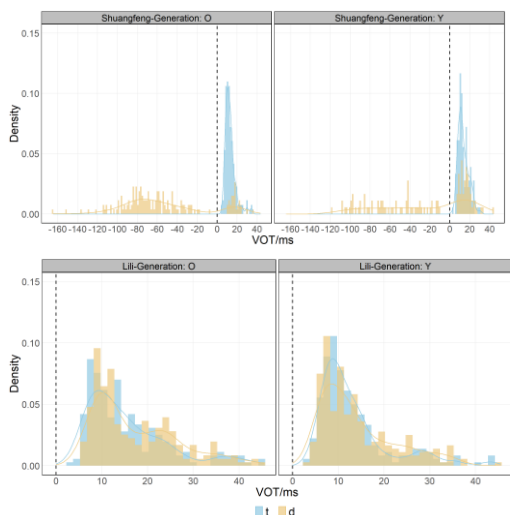


Figure 3: VOT distributions with density curves for /t/ and /d/ in SF (up) and LL (bottom) averaged over speakers of the old (left) and young (right) generations.

4.2. f_0 contours

Figure 4 depicts the f_0 realizations of lexical tones based on the onset voicing contrast. It is clear that the f_0 contours were different as a function of different lexical tones in both dialects [SF: $\chi^2=4222^{***}$; LL: $\chi^2=495^{***}$]. However, regardless of Generation [SF: $\chi^2=1.2^{n.s.}$; LL: $\chi^2=0.32^{n.s.}$], the f_0 contours

following syllables with onset /d/ were consistently lower than those following /t/, as confirmed by the results of the GCA, supporting the impressionistically observed co-occurrence constraints between lexical tones and laryngeal onsets.

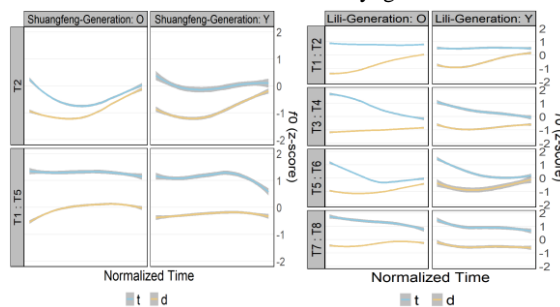


Figure 4: f_0 contours (z-score) after /t/ and /d/ in each lexical tone-carrying syllable in SF (left) and LL (right) speakers from the old and young generations. Gray areas indicate $\pm SE$.

4.3. CQ

Figure 5 illustrates the mean CQ values at three vowel positions within each lexical tone-carrying syllable for both generations. There were significant main effects for Consonant [SF: $\chi^2=27.9^{***}$; LL: $\chi^2=38^{***}$] and Position [SF: $\chi^2=55.7^{***}$; LL: $\chi^2=414^{***}$], as well as significant interactions for Consonant with Generation [SF: $\chi^2=42.7^{***}$; LL: $\chi^2=22.4^{***}$] and Consonant with Position [SF: $\chi^2=4.25^*$; LL: $\chi^2=32.4^{***}$] in both dialects.

These results indicated that CQ values after /t/ and /d/ differed irrespective of dialects. However, such differences were not consistent across generations and positions. Specifically, in SF, speakers of the old generation produced similar CQ values, while CQ values after /d/ produced by speakers of the young generation were significantly lower than those after /t/. In LL, the generational differences between /t/ and /d/, however, were reversed. Furthermore, all differences were most prominent at the one-third point, but reduced at the middle point, and vanished at the two-third point of the vowel.

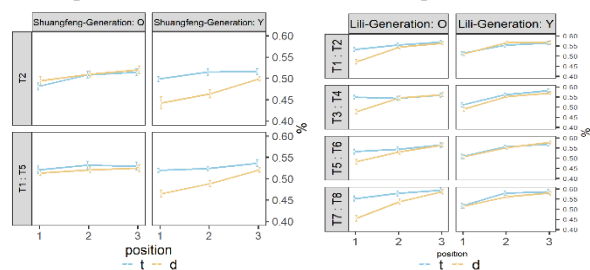


Figure 5: Mean CQ of three positions (1: one-third; 2: middle; 3: two-thirds) in target syllables of SF (left) and LL (right) speakers from the old and young generations. Error bars represent the standard error of the mean.

5. Discussion and conclusions

Our results confirmed the co-existence of tonal and voicing contrasts in Shuangfeng Xiang and Lili Wu Chinese realized with multiple phonetic cues, involving laryngeal timing (VOT), tonal identity (f_0), and phonatory state (CQ). However, the employment of these phonetic cues is language-specific (varying by dialect) and generation-specific (varying by speaker), as summarized in Table 2. The obstruent voicing contrast is consistently signaled by a binary high-low f_0 contrast.

The utilizations of VOT and CQ in the two dialects, however, are quite different.

Table 2: VOT, f_0 , and CQ for /t/ vs. /d/ by speakers of different generations in SF and LL.

Dialect	Generation	VOT	f_0	CQ
SF (Shuangfeng Xiang)	Old	lead vs. predominant lead tokens	high vs. low	modal
	Young	lead vs. fewer lead tokens		modal vs. breathy
LL (Lili Wu)	Old	lag tokens only		modal vs. breathy
	Young	lag tokens only		modal

Three remarkable generational differences are worth noting: (i) In SF, younger speakers exhibit more devoicing of /d/, indicated by a significant increase of positive VOT tokens for /d/. (ii) Younger speakers in SF display a breathier phonation for /d/, as evidenced by a significant decrease in CQ. (iii) In LL, younger speakers show a more modal phonation for /d/ with an increase of CQ, indicating a shift toward a clearer voicing in their pronunciation of /d/. These findings hence highlight dynamic patterns of cue reweighting in voicing (signaled via VOT) and phonation (signaled via CQ) for the phonetic implementation of the voicing contrast in the two dialects, possibly reflecting different stages of how the voicing contrast may maintain or disappear. The possible developmental trajectory of the voicing contrast, varying from the old-generation SF speakers to the young-generation LL speakers, may be hypothesized to go through four stages.

Stage I: Represented by old-generation speakers of SF, who predominantly produce negative VOT without significant breathiness (indicated by CQ) in the following vowel.

Stage II: Represented by young-generation SF speakers, who produce fewer negative-VOT tokens and shorter negative-VOTs. Furthermore, they enhance breathiness over the following vowel, but only over the first half. A trading relationship between VOT and CQ was further tested by a series of Pearson’s tests [old: $r=-0.66^{***}$; young: $r=-0.72^{***}$], suggesting that speakers who produced more positive VOTs tended to have lower CQs. The cue-reweighting process for signaling the voicing contrast reflects the inhibition of the VOT-led cue but the enhancement of the breathiness cue. Similar patterns have been observed in a few Southeast Asian languages, such as Cao Bằng Tai [11].

Stage III: Represented by old-generation speakers of LL, who produce all ‘voiced’ obstruents with positive VOTs but with a significantly higher level of breathiness over the first half of the following vowel.

Stage IV: Represented by young-generation speakers who keep identical patterns of VOT realizations, but with decreased breathiness over the first half of the following vowel. The breathy-phonation cue for signaling the voicing contrast is disappearing. Similar patterns have been reported in other Northern Wu Chinese, such as Shanghainese [30] and Suzhounese [31].

This four-stage model does not align with the emergence of lexical tonal contrasts found in atonal languages. In those languages, speakers who typically produce fewer VOT-lead tokens, along with shorter lead VOTs for the voiced category, often exhibit significant and systematic f_0 differences after phonologically voiceless and voiced plosives to convey the voicing contrast [6, 7, 32]. In languages with established lexical tones, a pertinent question arises: Do similar f_0 differences emerge in response to changes in VOT for the voiced category, potentially prompting subsequent adjustments to the lexical tonal system? Results in SF suggest a negative answer. Figure 6 illustrates f_0 contours for /d/ in two VOT categories, namely

lead VOT and lag VOT. Results of GCA showed insignificant effects on all time terms between the two f_0 contours. Such similarities are held across generations and lexical tones. These findings indicate that f_0 differences are quite stable and do not involve the cue-reweighting process of the voicing contrast, probably due to its primary function in serving lexical tonal contrasts in tone languages.

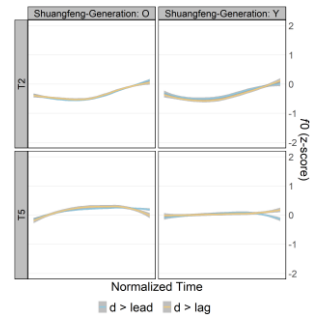


Figure 6: f_0 contours (z -score) after /d/ in T2 (top) and T5 (bottom) in SF speakers from the old (left) and young (right) generations. Gray areas indicate $\pm SE$.

In summary, in languages like Shuangfeng Xiang and Lili Wu Chinese, where tonal and voicing contrasts coexist, laryngeal timing (in terms of voice onset time) and phonatory state (in terms of contact quotient of vocal folds) are beginning to exhibit flexibility in signaling the voicing contrast through cue-reweighting processes. In production, speakers can actively adjust the weighting between negative VOT and breathier phonation to maintain the voicing contrast. As breathiness declines for voiced onsets, the voicing contrast may become extinct, and the laryngeal obstruent contrast is ultimately cued only by f_0 distinctions. Taken together, our results reveal a potential intermediate stage before the complete transphonologization of laryngeal contrasts into lexical tones, lending support to the laryngeal-based model of tonal development [12]. The rise and fall of the voicing contrast and their relationships with the emergence and development of the lexical tonal contrast can vary and may show areas of linguistic convergence. Further longitudinal surveys are needed to trace more variations in different linguistic areas, as well as the interaction of more segmental properties (such as vowel quality) with lexical tones [33, 34].

6. Acknowledgements

We would like to thank all our participants for making this study possible. M.S is currently supported by the National Social Science Fund (22CYY012) and Y.C by the Netherlands Organization for Scientific Research (V.I.C.181.040).

7. References

- [1] P. A. Keating, "Phonetic and phonological representation of stop consonant voicing," *Language*, vol. 60, no. 2, pp. 286–319. 1984.
- [2] T. Cho, D. H. Whalen and G. Docherty, "Voice onset time and beyond: Exploring laryngeal contrast in 19 languages," *Journal of Phonetics*, vol. 72, pp. 52–65. 2019.
- [3] B. H. Repp, "Phonetic trading relations and context effects: New experimental evidence for a speech mode of perception," *Psychological Bulletin*, vol. 92, no. 1, pp. 81–110. 1982.
- [4] M. Clayards, "Individual talker and token covariation in the production of multiple cues to stop voicing," *Phonetica*, vol. 75, no. 1, pp. 1–23. 2018.
- [5] J. Gao and T. Arai, "Plosive (de-)voicing and f₀ perturbations in Tokyo Japanese: Positional variation, cue enhancement, and contrast recovery," *Journal of Phonetics*, vol. 77, <https://doi.org/10.1016/j.wocn.2019.100932>. 2019.
- [6] Y. Kang, "Voice Onset Time merger and development of tonal contrast in Seoul Korean stops: A corpus study," *Journal of Phonetics*, vol. 45, pp. 76–90. 2014.
- [7] A. W. Coetzee, P. S. Beddor, K. Shedden, W. Styler and D. Wissing, "Plosive voicing in Afrikaans: Differential cue weighting and tonogenesis," *Journal of Phonetics*, vol. 66, pp. 185–216. 2018.
- [8] L. M. Hyman, "Phonologization," in A. G. Juiland (ed.), *Linguistic Studies Offered to Joseph Greenberg on the Occasion of his Sixtieth Birthday*, vol. 2, Anma Libri, 1976, pp. 407–418.
- [9] Y. Chen, "How does phonology guide phonetics in segment–f₀ interaction?" *Journal of Phonetics*, vol. 39, no. 4, pp. 612–625. 2011.
- [10] M. Brunelle and J. P. Kirby, "Tone and phonation in Southeast Asian languages," *Language and Linguistics Compass*, vol. 10, no. 4, pp. 191–207. 2016.
- [11] P. Pittayaporn and J. P. Kirby, "Laryngeal contrasts in the Tai dialect of Cao Bang," *Journal of the International Phonetic Association*, vol. 47, no. 1, pp. 65–85. 2017.
- [12] G. Thurgood, "Vietnamese and tonogenesis: Revising the model and the analysis," *Diachronica*, vol. 19, no. 2, pp. 333–363. 2002.
- [13] X. Xiang 向熹, "湖南双峰县方言 [Hunan Shuangfeng dialect]," *语言学论丛* [Essays on Linguistics], vol. 4, pp. 134–171. 1960.
- [14] Y.-R. Chao 赵元任, *现代吴语的研究* [Studies in the modern Wu dialects]. Beijing: Tsing Hua College Research Institute, 1928.
- [15] X. Zhu 朱晓农 and X. Zou 邹晓玲, "清浊同调还是气声分调——在音节学和类型学普适理论中安排湘语白话的声调事实 [One tone with onset voicing contrast or two tones with vowel breathy contrast]," *南方语言学* [South Linguistics], vol. 12, pp. 1–10. 2017.
- [16] M. Shi and Y. Chen, "Lili Wu Chinese," *Journal of the International Phonetic Association*, vol. 52, no. 1, pp. 157–179. 2022.
- [17] P.-H. Ting, "Some aspects of tonal development in Chinese dialects," *Bulletin of the Institute of History and Philology*, vol. 53, no. 4, pp. 629–644. 1982.
- [18] J. Yuan 袁家骅, *汉语方言概要* [A synopsis of Chinese dialects]. Beijing: Script Reform Press, 1960.
- [19] S. A. Wurm, R. Li, T. Baumann and M. W. Lee, *Language Atlas of China*. Hong Kong: Longman, 1987.
- [20] Chao, Y.-R. "ə sistim əv 'toun-letəz'," [A system of 'tone-letters'] *Le Maître Phonétique*, vol. 8, pp. 24–27. 1930. Reprinted in *方言* [Dialects], no. 2, pp. 81–83. 1980.
- [21] J. Cao and I. Maddieson, "An exploration of phonation types in Wu dialects of Chinese," *Journal of Phonetics*, vol. 20, no. 1, pp. 77–92. 1992.
- [22] Y. Zhao and D. Jurafsky, "The effect of lexical frequency and Lombard reflex on tone hyperarticulation," *Journal of Phonetics*, vol. 37, no. 2, pp. 231–247. 2009.
- [23] W. Labov, *Principles of Language Change: Internal Factors*. Oxford: Blackwell. 1994.
- [24] W. Pan 潘悟云, L. Li 李龙 and X. Han 韩夏, *斐风语言田野调查系统* [FieldPhone: A software for language fieldwork]. <http://www.eastling.org/>. 2015.
- [25] P. Boersma and D. Weenink, *Praat: Doing Phonetics by Computer*, <http://www.fon.hum.uva.nl/praat/>. 2018.
- [26] Y.-L. Shue, P. A. Keating, C. Vicens and K. Yu, "VoiceSauce: A program for voice analysis," in W.-S. Lee and Z. Eric (eds.), *Proceedings of the 17th International Congress of Phonetic Sciences*, City University of Hong Kong, China, 2011, pp. 1846–1849.
- [27] H. Tehrani, *EGGWorks: A Program for Automated Analysis of EGG Signals*, <http://phonetics.linguistics.ucla.edu/facilities/physiology/egg.htm>. 2009.
- [28] P. A. Keating, C. M. Esposito, M. Garellek, S. ud D. Khan and J. Kuang, "Phonation contrasts across languages," *UCLA Working Papers in Phonetics*, vol. 108, pp. 188–202. 2010.
- [29] C. M. Esposito, "An acoustic and electroglottographic study of White Hmong tone and phonation," *Journal of Phonetics*, vol. 40, no. 3, pp. 466–476. 2012.
- [30] J. Gao, "Sociolinguistic motivations in sound change: On-going loss of low tone breathy voice in Shanghai Chinese," *Papers in Historical Phonology*, vol. 1, pp. 166–186. 2016.
- [31] C. Ge, W. Xu, W. Gu, P. Mok. "The change in breathy voice after tone split: A production study of Suzhou Wu Chinese," *Journal of Phonetics*, vol. 98, <https://doi.org/10.1016/j.wocn.2023.101239>. 2023.
- [32] J. P. Kirby, "Onset pitch perturbations and the cross-linguistic implementation of voicing: Evidence from tonal and non-tonal languages," *Journal of Phonetics*, vol. 71, pp. 326–354. 2018.
- [33] J. Kuang and A. Cui, "Relative cue weighting in production and perception of an ongoing sound change in Southern Yi," *Journal of Phonetics*, vol. 71, pp. 194–214. 2018.
- [34] M. Brunelle, T. Tân, J. P. Kirby and D. Giang, "Transphonologization of voicing in Chru: Studies in production and perception," *Laboratory Phonology: Journal of the Association for Laboratory Phonology*, vol. 11, no. 1, pp. 1–33. 2020.