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ILLUSTRATION OF THE IPA

Zhongjiang Chinese

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Introduction

Zhongjiang Chinese (中江话) is a variety of Mandarin Chinese, one of the ten language families in China (Mandarin, Cantonese, Xiang, Min, Gan, etc.,). Sometimes the term "Mandarin" is also used to refer to the national lingua franca "Putonghua". We refer to the national lingua franca as "Standard Mandarin" and reserve the term Mandarin (官话) to refer to the language family, as distinct from other families, e.g., Cantonese, Xiang, Min, Gan, etc. Within Mandarin, Zhongjiang is a member of the Southwestern dialects (西南官话) (*Language Atlas of China 1988*). It is spoken in the urban areas of Zhongjiang county (中江县) in Sichuan province (四川省) of China. Zhongjiang county belongs to the Deyang (德阳) region, which is located in the middle of Sichuan province, about 100 kilometers northeast from the provincial capital of Chengdu (成都). Zhongjiang is just beyond the Chengdu Plain (成都平原), so the terrain is mostly hilly, with little flat land. It has a population of 1.37 million residents and an area of 2,200km^2 (data from Zhongjiang official website, updated July 7, 2021).

Existing studies on Zhongjiang Chinese reporting aspects of the phonetics include the *Sichuan Dialects Investigation Report* (Yang, 1984), based on data recorded in 1946. The data for this report was collected in what was called Dasang town, currently Longtai town, which represents the rural village dialect and is phonetically different from the urban areas of Zhongjiang county. Longtai (formerly Dasang) is 20 kilometers southeast of Zhongjiang City. The Yang (1984) report is based on one speaker, who also lived in Chengdu for six years and in Emei (a county in Southwest Sichuan) for three years. Another phonetic description is the *Phonology of Sichuan Dialects* (1960), which recorded about 150 dialects in Sichuan province including Zhongjiang county. The aim of that work was to identify the variation across varieties in consonants, vowels and tones by comparing cognate words.

The aim of the present illustration is to zoom in on one of these varieties.

Figure 1. (Colour online) (A) Map of China with Sichuan province indicated in grey; (B) Inset of the DeYang region of Sichuan, which contains Zhongjiang, including Zhongjiang City, indicated by a double circle, and surrounding towns, indicated by single circles.

Although Zhongjiang is typically characterized as a Mandarin variety, it has some phonetic features that are shared with the Xiang language family. Xiang is a distinct family of languages, primarily spoken in Hunan province. Arguably, the shared phonetic features between Zhongjiang and Xiang are related to language contact. Mass immigration in the Qing dynasty, approximately 400 years ago, brought large numbers of Xiang speakers from Hunan province to Sichuan province, including to areas around Zhongjiang (Cao,

1997; Zhou, 2013).[1] Today, there remain a few Xiang language islands in the rural areas of Zhongjiang county, such as Yongxing (Cui, 1985). Due to the local prestige of Southwestern Mandarin, Xiang language islands are becoming endangered, and younger speakers may be less likely to acquire Xiang-influenced phonetic features, even in the Zhongjiang variety (see also Rao & Shaw, 2021).

This current article is based on recordings from five speakers (three male) of Zhongjiang Chinese, producing a range of different materials. Of the male speakers, Speaker 1 (Sp 1) was born in 1960, Speaker 2 (Sp 2) was born in 1959, and Speaker 3 (Sp 3) was born in 1997. Of the two females, one (Sp 4) was born in 1953 and the other was born in 1991 (Sp 5). All five speakers were born and raised in Zhongjiang City (double circle in Figure 1), where they also currently reside. All speakers use Zhongjiang Chinese in their daily lives. We selected older speakers, particularly those with less formal education, to minimize the influence of Standard Mandarin. Speakers were also screened by the first author to make sure that they were representative of the urban Zhongjiang variety. Additionally, at the end of the recording sessions, we administered part of a standardized test, used for assessing Standard Mandarin proficiency. This involves reading a story designed to elicit features of Standard Mandarin. There was variation across speakers in Standard Mandarin proficiency. Most of the examples submitted with this article are drawn from speaker 2, who showed the least Standard Mandarin proficiency, reading the Standard Mandarin passage with phonetic features characteristic of the Zhongjiang variety.

The tradition in Chinese dialectology, including past work on Southwest Mandarin has been to describe consonants, vowels, and tones in their surface phonetic form; thus, most past descriptions can be interpreted as surface allophones which may or may not support a phonemic contrast. In this description, we take the distribution of allophones into account in arriving at a phonemic inventory. As a result, our phonemic description contains considerably fewer consonants than past descriptions. We describe systematic allophonic variation after introducing the phonemic inventory.

In this article, we sometimes explicitly contrast the pronunciation of Zhongjiang Chinese with Standard Mandarin. To make it clear which variety an IPA transcription refers to, we adopted the convention of notating Zhongjiang Chinese transcriptions with "(ZC)" and Standard Mandarin with "(SM)". Transcriptions that are not notated with this convention refer to Zhongjiang Chinese.

Consonants

In the consonant table, square brackets show allophones with restricted distributions, which can be derived from other consonants, as we describe in greater detail below. Briefly, [w] and [j] are in complementary distribution with the vowels [u] and [i]; [ɲʲ] occurs only in the environment preceding [i]/[j]; and, [l], which is variably nasalized, [l̃], surfaces only in onset position, in complementary distribution with [n]. Although these consonants have restricted distributions, we listed them in the table in square brackets as they are often included in descriptions of related Mandarin varieties.

[1] There was another earlier wave of migration during the Ming dynasty. Due to war, famine, plague, etc., the population in Sichuan province decreased dramatically, prompting special government policies (for example, forcing immigrating or encouraging volunteers) in order to recover production and open up unused land for farming. The Ming immigration (roughly 1369-1391) was mainly from modern day Hubei. The later migration in early Qing dynasty (about 1670-1775) was mainly from modern day Hubei and Hunan, with smaller groups from other areas (e.g., Guangdong, Jiangxi provinces). These two main waves of immigration are named as "Huguang Fill Sichuan", and contributed to the modern Sichuan dialect. Most relevant for our discussion here are the Xiang-speaking migrants, who were primarily from Hunan, but the migrant population also brought other language varieties from Huguang to Sichuan.

The consonant table below depicts the inventory of Zhongjiang Mandarin. Square brackets indicate consonants with limited (non-contrastive) distributions.

	Bilabial	Labio-dental	Alveolar	Denti-alveolar	Alveolo-palatal	Velar
plosive	p p^h		t t^h			k k^h
affricate				ts ts^h	tɕ $tɕ^h$	
nasal	m		n		[ȵʲ]	ŋ
fricative		f		s z	ɕ	x
approximant	[w]				[j]	
lateral			[l]			

	IPA	Simplified Chinese	English
p	$pɑ^{31}$	八	‘eight’
p^h	$p^hɑ^{31}$	爬	‘crawl’
t	tu^{31}	毒	‘poison’
t^h	t^hu^{31}	图	‘painting’
k	ko^{31}	鸽	‘pigeon’
k^h	k^ho^{31}	壳	‘shell’
ts	$tsɑ^{31}$	杂	‘mixed’
ts^h	$ts^hɑ^{31}$	茶	‘tea’
tɕ	$tɕi^{31}$	集	‘collection’
$tɕ^h$	$tɕ^hi^{31}$	七	‘seven’
m	me^{31}	麦	‘wheat’
[ȵʲ][2]	$ȵʲi^{31}$	泥	‘mud’
ŋ	$ŋo^{31}$	鹅	‘goose’
n	$zən^{31}$	人	‘people’
[l]	$lɑ^{31}$	辣	‘spicy’
f	fu^{31}	佛	‘the Buddha’
s	$sɑ^{31}$	杀	‘kill’

[2] In the text below, we propose that this is a surface realization of /ŋ/.

z	ze^{31}	热	'hot'
ɕ	ɕi^{31}	习	'practice'
x	xo^{31}	河	'river'
[j]	jɑ^{31}	牙	'tooth'
[w]	wɑ^{31}	娃	'kids'

Plosives

Plosives are produced at three places of articulation in Zhongjiang Chinese: bilabial /p pʰ/, as in [pɑ^{31}] 八 'eight', [pʰɑ^{31}] 爬 'crawl'; alveolar /t tʰ/, as in [te^{31}] 得 'to get', [tʰe^{31}] 特 'special'; and, velar /k kʰ/, as in [ko^{31}] 各 'each', [kʰo^{31}] 壳 'shell'.

At each place of articulation, there is a contrast in aspiration. Table 1 reports the mean and standard deviation of Voice Onset Time (VOT) for aspirated and unaspirated plosives at each place of articulation. The mean and standard deviation were calculated across monosyllabic words (between 27 and 54 words per phoneme) for one male speaker. The list of words entering the analysis is provided in the appendix.

Table 1. VOT of aspirated and unaspirated plosives in different places of articulation. The items that contributed VOT values, 258 monosyllabic words, are listed in appendix 1. All VOT values are in milliseconds (ms).

	bilabial		denti-alveolar		velar	
	unaspirated	aspirated	unaspirated	aspirated	unaspirated	aspirated
mean (SD)	19 (16)	147 (41)	19 (9)	120 (42)	10 (6)	98 (16)
N =	52	30	52	43	54	27

Our impression is that aspiration in Zhongjiang is generally stronger than in Mandarin, but this would require a more comprehensive study to test. The VOT measures for this speaker, averaged across a single production of 27–54 words per category, are particularly long for bilabial and denti-alveolar plosives, as compared with published data on other Chinese varieties. For Tianjin Mandarin, Li (2019) reports the following mean VOT values: /pʰ/ 91 ms, /tʰ/ 100 ms, /kʰ/ 116 ms. For Standard Mandarin, Rochet & Fei (1991) report /pʰ/ 99.6 ms, /tʰ/ 98.7 ms, and /kʰ/ 110.3 ms. The observation that bilabial and denti-alveolar plosives have particularly heavy aspiration in Zhongjiang is consistent with past reports (Yang, 1984). Additionally, some cognate words are produced as aspirated in Zhongjiang but unaspirated in Standard Mandarin: e.g., [pʰɑ^{31}] 拔 'to pull' (ZC) vs. [pa^{35}] (SM), [tʰɐɯ^{451}] 抖 'to tremble' (ZC) vs. [təɯ^{214}] (SM); [tɕʰe^{31}] 截 'section' (ZC) vs. [tɕje^{35}] (SM); [tsʰɑɯ^{324}] 造 'to create' (ZC) vs. [tsau^{51}] (SM).

Affricates

Affricates in Zhongjiang Chinese have two places of articulation: denti-alveolar /ts tsʰ/,[3] as in [tsɑ^{31}] 杂 'mixed' and [tsʰɑ^{31}] 茶 'tea', which involve the tongue tip generating frication

[3] To highlight the denti-alveolar place of articulation, these consonants could also be transcribed with the dental diacritic, as /t̪s t̪sʰ/. Because there is not a contrast with an alveolar place of articulation and to minimize the use of diacritics, we have transcribed them without the dental diacritic throughout this illustration.

at the teeth, and alveolo-palatal /ɕ ɕʰ/, as in [ɕi^{31}] 集 'collection', [ɕe^{31}] 节 'holiday', [ɕʰi^{31}] 七 'seven', [ɕʰe^{31}] 切 'to cut'. Place of articulation for affricates is contrastive before all vowels except for /u/. Before /u/, only the denti-alveolars are found: [tsu^{31}] 竹 'bamboo', [tsʰu^{31}] 出 'come out'. Denti-alveolars (but not alveolo-palatals) can also be followed by a labiovelar glide, as in [tswɑŋ^{34}] 装 'pretend' and [tsʰwɑŋ^{324}] 窗 'window'. In addition to these two affricate series, Standard Mandarin Chinese also has retroflex (post-alveolar) affricates, which contrast with the denti-alveolar, as in [tsɑ^{35}] 杂 'mixed' and [tʂɑ^{35}] (SM) 炸 'fry'; whereas, in Zhongjiang, [tsɑ^{31}] represents both of these meanings.

We also note that the denti-alveolar affricate as well as the denti-alveolar fricatives (described below) condition allophonic variation in the following vowel /i/. In denti-alveolar contexts, /i/ surfaces as an 'apical vowel', which we represent as [ɻ̩]: (affricate) [tsɻ̩^{31}] 汁 'juice', [tsʰɻ̩^{31}] 吃 'eat'; (fricative) [sɻ̩^{34}] 丝 'silk'. Although we do not have articulatory data for ZC, other Chinese varieties have shown that the tongue position and shape for the apical vowel is nearly the same as for preceding fricatives/affricatives, i.e., denti-alveolar in the denti-alveolar fricative/affricate context and retroflex in the retroflex fricative/affricate context (see Faytak & Lin 2015 for Standard Mandarin and Faytak 2018 for Suzhou Chinese).

Finally, we note that in longer words the affricates are sometimes produced without full closure, surfacing instead as fricatives: for example /i^{53}tɕʰɑ̃^{31}/ 以 前 'before' surfaces as [ji^{45}ɕʰɑ̃^{31}].

Nasals

Nasals occur at four places of articulation, bilabial [m], alveolar [n], alveopalatal [ɲʲ], and velar [ŋ], and they alternate in some cases with laterals [l]. All of these consonants are often produced with an oral release. The oral release is particularly prevalent in the environment of /i/ and /j/. Since the alveopalatal nasal only occurs in this environment, we transcribed it as [ɲʲ] throughout, including in the consonant chart.

The bilabial /m/ can only occur in syllable onset position, where it is often pronounced with an oral release, i.e., as [mᵇ]. This is also noted in *The Report of Sichuan Dialect* (Yang, 1984). Figure 2 shows the waveform (top) and spectrogram (bottom) for a representative token, the /m/ from [mᵇe^{31}] 麦 'wheat'. A decrease in energy in the upper formants can be observed in the spectrogram just before the release burst (the release burst is visible in the waveform). In particular, when we play back this token from the temporal mid-point of the /m/, we have the percept of /b/, which is not the case for fully nasalized tokens in other varieties. Although the nasals can be perceived as pre-nasalized stops, due to the oral release, they function phonologically in Zhongjiang as nasals.

In Zhongjiang, the velar nasal /ŋ/ can occur in both onset position, as in [ŋᵍɑɯ^{31}] 熬 'to stew', and coda position, as in [fɑŋ^{31}] 房 'house', (also [ŋᵍɑŋ^{31}] 昂 'raise'). As with the other nasals, the velar nasal in onset position often has an oral release, [ŋᵍ]. Figure 3 compares /ŋ/ across positions in the same word: [ŋᵍɑŋ^{31}] 昂 'raise'. In onset position, the bandwidth of the first formant is wide, characteristic of the nasal formant, but there is little energy at higher frequencies, particularly near (immediately preceding) the release burst. The syllables that begin with velar nasals in Zhongjiang are typically onsetless in Mandarin Chinese, for example [ŋᵍai^{324}] 爱 'love' (ZC) corresponds to [ai^{451}] 爱 'love' (SM). The presence of the velar nasal in onset position is another way in which Zhongjiang differs from Mandarin Chinese and from North Mandarin dialects in general.

The Zhongjiang variety also has an alveolo-palatal nasal, [ɲʲ] with a limited distribution. [ɲʲ] only occurs before the front high vowel, [i], or palatal glide, [j]. In these environments, it contrasts with the lateral, [l]: [ɲʲi^{31}] 泥 'mud' (ZC) forms a minimal pair with [lᵈi^{31}] 梨 'pear' (ZC), which, like the nasals, often has an oral release. Standard Mandarin Chinese,

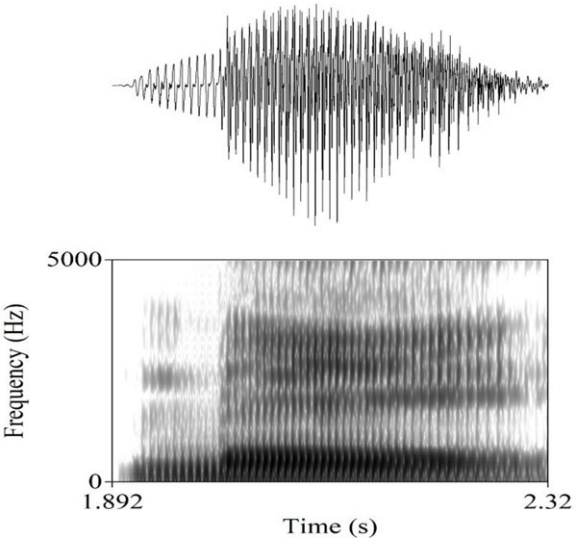

Figure 2. Waveform (top) and spectrogram (bottom) of [$m^{b}e^{31}$] 'wheat'.

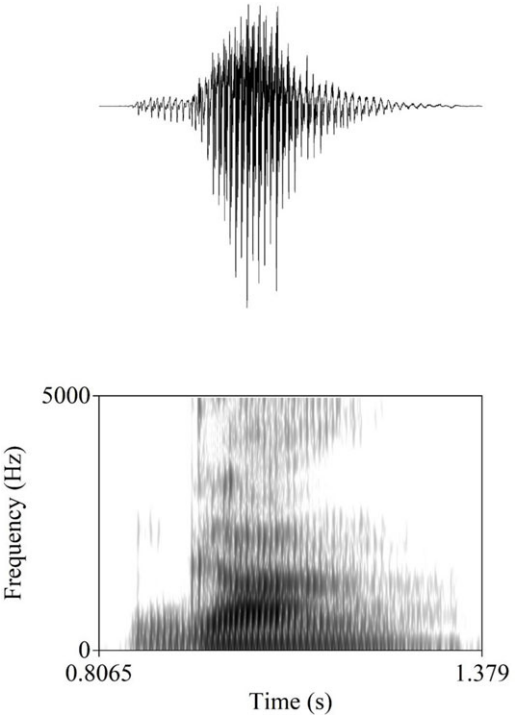

Figure 3. Waveform (top) and spectrogram (bottom) for [$ŋ^{g}ɑŋ^{31}$] 昂 'raise' illustrating velar nasals in onset and coda position, within the same word. The onset nasal has a wider first formant bandwidth and less energy at higher frequencies than the coda nasal. See sound file '52-raise'.

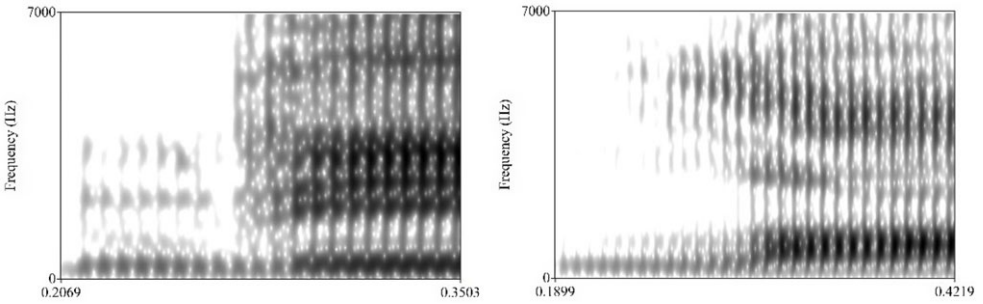

Figure 4. Comparison of initial [l] in different vowel environments: /i/ as in [l^{d}i ^{31}] 立 'stand' (left) and /ɑ/ as in [lɑ^{31}] 辣 'spicy' (right).

in contrast, does not have an alveolo-palatal nasal. Cognate words in Standard Mandarin are pronounced either with a denti-alveolar nasal, /n/, e.g., [ni^{35}] 泥 'mud' (SM) or without an initial consonant, e.g,. [i^{51}] 艺 'art' (SM), although variable pronunciations of /n/ as /ɲ/ have also been described for Standard Mandarin. For example, Duanmu (2007) describes a pronunciation of [njan^{35}] 年 'year' as [ɲan^{35}] (SM).

The alveolar nasal [n] is generally restricted to coda position. However, the lateral approximant, which does occur in initial position, can be nasalized, [l̃], and even produced with an oral release, [l^{d}], just like the initial nasals at other places of articulation. The degree of nasalization may vary according to context. Various patterns of nasal-lateral merger and blending have been documented across Sichuan varieties of Southwest Mandarin. Wang (2004:151) noted that merger of /n/ with /l/ in Sichuan varieties is common. The merged phoneme is usually recorded as /n/, and it is reported that merger of nasal /n/ with lateral /l/ could happen in any context. However, in some varieties, there are also intermediate sounds, i.e., nasalized laterals or lateralized nasals. *The phonology of Sichuan dialect* (1960:5) recorded that the /l/ in Sichuan dialect has three varieties: [n], [l] and [l̃], the usage of which varies across speakers as well as within speakers. Often, [n] tends to occur in front of /i/ or /y/, while [l] and [l̃] tend to occur before other, more open, vowels. This generalization is largely consistent with our observations of ZC.

We observe systematically different spectral patterns for [l]∼[l̃] across vowel contexts: /i/∼/j/ vs. others, e.g., /ɑ/. An example is shown in Figure 4. The left panel shows [l^{d}i^{31}] 立 'stand'; the right panel shows [lɑ^{31}] 辣 'spicy'. Differences include that the [l] in [li^{31}] shows the presence of high frequency energy, in the range of F2/F3 for [i], which are absent for [ɑ] in [lɑ^{31}]. Additionally, the F1 formant bandwidth is wider for [l] in [l^{d}i^{31}] than in [lɑ^{31}]. This may indicate greater nasal airflow in [l^{d}i^{31}] than in [lɑ^{31}] (for a review of acoustic correlates of nasality, see Styler (2017) and Carignan (2018)); however, F1 bandwidth can have many articulatory sources, including degree of lateralization. Despite possible differences in degree of nasalization across vowel contexts, we denote the Zhongjiang lateral as [l]∼[l^{d}].

Finally, we add that, in coda position, the place of oral articulation, alveolar vs. velar, of the nasal is dictated by vowel contrast, with the alveolar nasal following non-back vowels and the velar nasal following back vowels.

To summarize the nasal consonants, we present a table of allophones (Table 2). The first column summarizes the set of environments that condition variation. The top row lists phoneme to allophone mappings: (1) /n/ realized as [n]; (2) /n/ realized as [l]∼[l^{d}]; (3) /ŋ/ realized as [ɲ^{j}]; (4) /ŋ/ realized as [ŋ]; and, for completeness, (5) /m/ realized as [m^{b}]. The last three rows show the distributional facts in coda position, where /n/ is realized as [n] only

Table 2. Summary of the distribution of nasal consonant allophones.

	/n/ [n]	/n/ [l],[l^d]	/ŋ/ [$ɲ^j$]	/ŋ/ [ŋ], [$ŋ^g$]	/m/ [m^b]
onset before /i/, /j/	*	[$l^d i^{31}$] 梨 'pear' [$l^d jã^{31}$] 莲 'lotus'	[$ɲ^j i^{31}$] 泥 'mud' [$ɲ^j jã^{31}$] 年 'year'	*	[$m^b i^{451}$] 米 'rice' [$m^b jã^{31}$] 棉 'cotton'
onset before /u/	*	[lu^{324}] 路 'road'	*	*	[$m^b u^{451}$] 母 'mother'
onset before /w/	*	[$lwã^{451}$] 暖 'warm'	*	*	*
onset elsewhere before other vowels (not /i/, /u/)	*	[la^{31}] 辣 'spicy' [$lɔɯ^{31}$] 楼 'building' [lo^{31}] 落 'drop'	*	[$ŋ^g ai^{324}$] 爱 'love' [$ŋ^g e^{31}$] 额 'forehead' [$ŋ^g o^{31}$] 鹅 'goose'	[$m^b a^{451}$]马 'horse' [$m^b e^{31}$] 麦 'wheat' [$m^b o^{31}$] 磨 'grind'
coda following /i/, /e/	[tin^{34}] 钉 'nail' [$xɐn^{324}$] 恨 'hate'	*	*	*	*
coda following /u/	*	*	*	*	*
coda following /a/, /o/	* (c.f., [$fã^{31}$])	*	*	[$fɑŋ^{31}$] 房 'house' [$fɑŋ^{31}$] 房 'house'	*

Examples marked with an asterisk, '*', indicate a lexical gap; examples without * indicate an attested word.

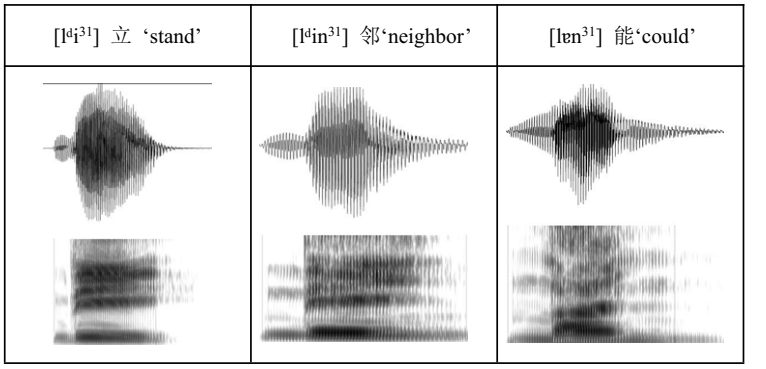

Figure 5. Comparison of initial [l] in words without (left) and with (center, right) a nasal coda.

following non-back vowels. Coda nasals in the back vowel environments of /ɑ/ and /o/ are realized as [ŋ], and no coda nasals occur after /u/. Since [n] and [ŋ] are in complementary distribution in coda position, it may be possible to analyze them as either /n/ or /ŋ/. In onset position, there are minimal pairs differentiating [lᵈ] from [ɲʲ] and [l] from [ŋ]. Both of these contrasts, we have analyzed as /n/ vs. /ŋ/, with [l] and [lᵈ] derived from /n/ and [ɲʲ] derived from /ŋ/.

We end the section on nasals with a brief comparison to other Mandarin varieties. In Standard Mandarin, there is a clear contrast between the alveolar lateral /l/ and the alveolar nasal /n/ in onset position: e.g., [lu^{51}] 鹿 'deer' vs. [nu^{35}] 奴 'slave'; [loŋ^{35}] 龙 'dragon' vs. [noŋ^{35}] 浓 'heavy'. Word pairs such as these are homophonous in the Zhongjiang variety. To our ears, the initial /n/ retains a lateral quality [l]~[l̃]. Figure 5 displays spectrograms for the relevant comparison. The distribution of spectral energy for the initial consonant is similar, even in the presence of a nasal coda (c.f., Xiangxiang Chinese, [Zeng, 2019]).

Finally, in coda position, Standard Mandarin shows a contrast in nasal place of articulation, e.g., /in/-/iŋ/, /ɐn/-/ɐŋ/ are contrastive, as in [ɕin^{55}] (SM) 新 'new' vs. [ɕiŋ^{55}] (SM) 星 'star' and [kɐn^{55}] (SM) 根 'root' vs. [kɐŋ^{55}] (SM) 耕 'plow'. The cognate words are homophones in Zhongjiang Chinese, where /in/-/iŋ/ are both pronounced as [in] and /ɐn/-/ɐŋ/ are both pronounced as either [oŋ] following labials onsets, [p], [pʰ], [m], [f], and as [ɐn] following all other onset consonants.[4]

Fricatives

There are five contrastive fricatives in Zhongjiang Chinese, /f/, /s/, /x/, /ɕ/, /z/. None of the fricatives can occur in coda position. Before /e/, there is a minimal quintuplet: [ɕe^{31}] 雪 'snow', [se^{31}] 色 'color', [ze^{31}] 热 'hot', [xe^{31}] 黑 'black' and [fe^{31}] 或 'or'. In the /i/ environment, there is a three-way contrast between /s/, /z/, and /ɕ/, with allophonic variation in the following vowel: /si/ surfaces as [sɻ̩], as in [sɻ̩^{34}] 丝 'silk'; /zi/ surfaces as [zɻ̩], as in [zɻ̩^{31}] 日 'sun'; and /ɕi/ surfaces as [ɕi], as in [ɕi^{34}] 西 'west'.

Figure 6 shows spectra of the five contrastive fricatives in the /e/ environment. /s/ has a peak in the spectrum around 3,600 Hz, which begins a plateau of relatively high amplitude in the frequency range from 3,600 Hz to 9,500 Hz. This contrasts with a lower frequency peak in /ɕ/. /z/ has an even lower frequency peak, presumably due to voicing, and a plateau of high amplitude energy from 2,700 Hz to 7,200 Hz. The velar fricative, /x/, is not voiced,

[4] There are a few exceptions to this pattern, with [ɐn] instead of [oŋ] following labials.

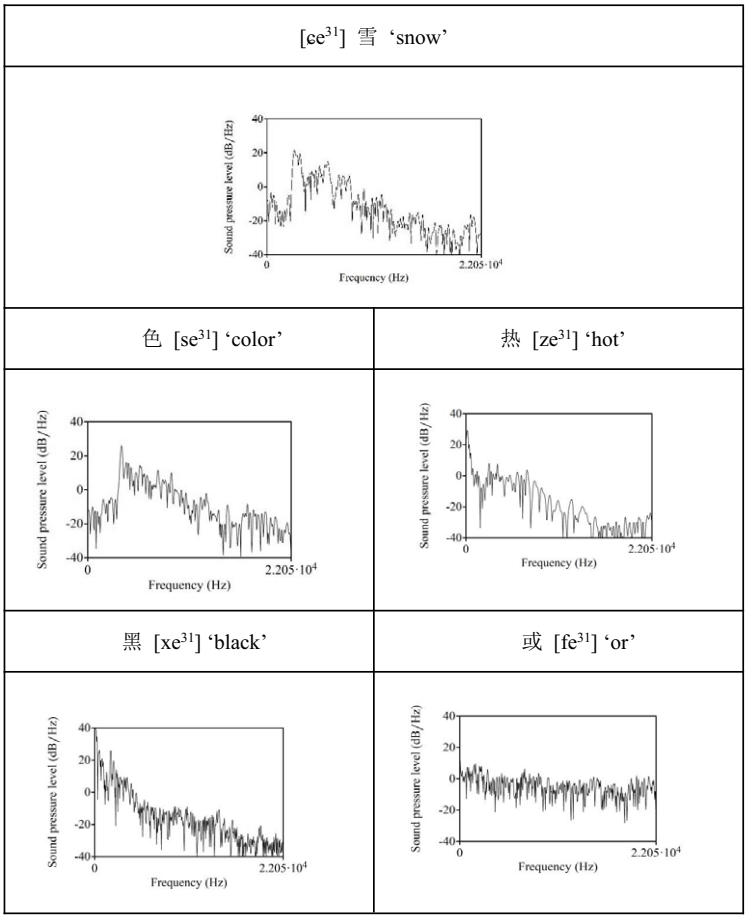

Figure 6. Spectra of five fricatives of Zhongjiang Chinese: /s/, /z/, /x/ and /f/.

but has low frequency energy peaks; amplitude falls sharply at higher frequencies, in contrast to the high amplitude energy plateaus for the coronal fricatives. The velar fricative /x/ may be realized as a uvular fricative [χ] when followed by a low vowel and falling tone, as in /xau3/ [χau^{451}] 好 'good'. Even outside of this environment, the place of articulation of /x/ is produced with a relatively posterior constriction, evidenced by the particularly low spectral center of gravity compared to other languages (Rao & Shaw, 2021). Finally, the spectrum for the labiodental, /f/, is diffuse, with relatively stable energy levels across frequencies. Although the common place of articulation of this fricative is labial-dental, bilabial variants have also been observed (Rao & Shaw, 2021).

The contrast between /f/ and /x/ is neutralized in some environments. The distribution of /f/ and /x/ is summarized in Table 3. The dominant pattern across speakers is that before /u/, only /f/ (and not /x/) can occur. We see the opposite pattern preceding the rime /oŋ/. In the environment of /oŋ/, only /x/ (and not /f/) can occur. Neither fricative can occur before /w/.

The distribution in Table 3 is the result of conditional mergers between /x/ and /f/. Velar fricatives in the environment of [w] were reinterpreted as /f/, e.g., [xwɑ^{31}] 滑 'slippery'--> [fɑ^{31}] 法 'law'; for a more detailed account of the development of the velar and labiodental

Table 3. Distribution of /f/ and /x/

	[f]	[x]
onset before /u/	[fu^{31}]	*
onset before /w/	*	*
onset before /o/	*	[xoŋ^{34}]
onset before /i/, /j/	*	*
onset elsewhere	[fɐɯ^{31}] [fɑ^{34}] [fe^{31}] [fai^{31}]	[xɐɯ^{31}] [xɑ^{34}] [xe^{31}] [xai^{31}]
coda	*	*

fricative distribution, including patterns of individual differences and discussion of historical development, see Rao and Shaw (2021). Acoustic measurements of the non-coronal fricatives in Zhongjiang Chinese are available in Rao et al. (2022).

We note that the voicing distinction between /s/ and /z/, the denti-alveolar fricatives, is the only pure voicing contrast in the language. Other Chinese varieties have more extensive voicing contrasts, including within the fricatives. For example, Shanghai Chinese, has a distinction in voicing across the stop and fricative series, including a voicing contrast for labiodental fricatives: e.g., in [vu^{3}] 父 'father' vs. [fu^{1}] 夫 'husband' (Chen & Gussenhoven, 2015). In Zhongjiang, some aperiodic energy can be observed in the high vowels, including /u/ but not so much that we would describe it as a [v] allophone of /u/.

Approximants

Zhongjiang Chinese has two approximants: the glides [w j], as in [wu^{451}] 五 'five', [je^{214}] 夜 'night'. These are in complementary distribution with the high vowels: [w] is in complementary distribution with [u]; [j] is in complementary distribution with [i]. The glides, [w] and [j], occur before vowels while the vowels, [u] and [i], occur elsewhere. Since it is not generally possible for consonants to surface as syllable nuclei (although see discussion of the "apical vowel"), we analyze the approximants as positional variants of the high vowels: /u/ and /i/.

In pre-vocalic position, there are some restrictions on the environments in which the glides can surface. Some restrictions apply only to [w], some apply only to [j], and some apply to both. Table 4 summarizes the attested and unattested vocalic environments of each glide.

[w] can precede rimes beginning with [e] (as in [we^{451}] 喂 'hello' and [kwe^{31}] 国 'country'), and [ɑ] (as in [wa^{34}] 蛙 'frog' and [kwɑ^{34}] 瓜 'melon'), except for [ɑɯ]; but does not occur before rimes beginning with [i], [u], [o]. Additionally, [w] can occur before [ɐn] (as in [kwɐn^{451}] 滚 'roll') but not before [ɐɯ].

[j] can precede all rimes beginning with [ɑ] (as in [l̃ jɑŋ^{451}] 凉 'chilly') and [o] (as in [jo^{31}] 药 'medicine') but it cannot occur before [i] or [u]. Additionally, [j] can occur before [e] (as in mje^{31}] 灭 'exterminate') and [ɐɯ] (as in [l̃jɐɯ^{451}] 料 'material') but not before [ei] and [ɐn]. There are also phonotactic restrictions on the onset consonants that precede [j]. Of

Table 4. Vowel environment of glides (see text for examples)

	[(C)w]	[(C)j]
ai, ɑ(ŋ), ã, e	attested	attested
ei, ɐn	attested	**unattested**
i(n), u	**unattested**	**unattested**
ɑɯ, ɐɯ, o(ŋ)	**unattested**	attested

the consonants represented in Table 1, only [p, p^h, t, t^h, tɕ, $tɕ^h$, m, n, [ɲʲ] ɕ] can precede [j]. This is the same set of consonants that can precede the vowel [i].

Some tokens of [j] in our recordings have a high level of frication. This is most common in words with homorganic vowels, e.g., /ji^{31}/ — 'one'. Although the voiced fricative variant of the palatal approximant is not consistently produced across Zhongjiang speakers, it's possible that it is more common in Zhongjiang than in other Mandarin varieties.

The above restrictions on glide distribution generalize to cases in which the glide is preceded by an onset consonant. For example, [w] can occur before /ai/, as in [wai^{324}] 外 'outside' but not before /ɑɯ/, ∗[waɯ], and this same restriction applies to [kw]; [$kwai^{324}$] 怪 'strange' is attested but ∗[kwɑɯ] is not. The restrictions therefore apply to the rime environment following the glide, even when the glide is incorporated into a complex onset.

The phonotactic restrictions on glide-vowel combinations cannot be stated with reference to the immediately following vowel only; it is necessary to state the entire rime. For example, [ɐɯ] cannot follow [w], but this is not due to a restriction on [w] and [ɐ] generally, because [ɐn] can, in fact, follow [w]. Similarly, after [j], [e] but not [ei] is permitted. Thus, the restrictions appear, at least in some cases, to refer to the entire rime as opposed to local combinations of a glide and a following vowel.

In many cognate words, Zhongjiang differs from Standard Mandarin in the presence/absence of a labiovelar glide. Differences include cases in which a [w] in Standard Mandarin is absent in Zhongjiang and cases in which a [w] in Zhongjiang is absent in Mandarin. There are two main environments for this variation.

One is the rime environment [ɐn]. In this environment, several words that contain a glide in Standard Mandarin, lack a corresponding glide in Zhongjiang. For example, the following Zhongjiang words are produced without a glide: [$ts^hɐn^{34}$] 村 'village',[5] [$ts^hɐn^{324}$] 寸 'inch', [$tɐn^{34}$] 蹲 'squat', [$lɐn^{31}$] 轮 'wheel', [$sɐn^{451}$] 笋 'bamboo shoot', [$sɐn^{34}$] 孙 'grandson', [$t^hɐn^{34}$] 吞 'swallow', [$ts^hɐn^{34}$] 春 'spring'. The Standard Mandarin cognates of these words are produced with a glide: [$ts^hwɐn^{55}$] (SM) 村, [$ts^hwɐn^{451}$] (SM) 寸, [$twɐn^{55}$] (SM) 蹲, [$lwɐn^{35}$] (SM) 轮, [$swɐn^{214}$] (SM) 笋, [$swɐn^{55}$] (SM) 孙, [$t^hwɐn^{55}$] (SM) 吞, [$ts^hwɐn^{34}$] (SM) 春. This variation is not due to a categorical prohibition of the labiovelar glide before [ɐn]. As noted in Table 4, the labiovelar is allowed in this environment. Although it is absent in some words, it is retained in others. The following words contain a labiovelar glide in Zhongjiang, making them homophonous with their Standard Mandarin pronunciation: [$kwɐn^{451}$] 滚 'roll'/[$wɐn^{34}$] 温 'warm'/[$kwɐn^{324}$] 困 'sleepy'.

A second environment for labiovelar glide variation is between a lateral consonant and the diphthong [ei]. In this environment we observe a labiovelar glide in Zhongjiang that is

[5] Although it lacks a glide, the fricative in [$ts^hɐn34$] 村 'village' is produced with a more posterior place of articulation than the other denti-alveolar affricates; the same is true for [$ts^hɐn^{324}$] 寸 'inch'. Thank you to AE Matt Gordon for pointing this out.

absent from cognate words of Standard Mandarin. Examples include: [lwei^{31}] 雷 'thunder', [lwei^{324}] 累 'tired', [lwei^{324}] 泪 'tears', [lwei^{451}] 垒 'build', [lwei^{324}] 内 'inner', which are pronounced without the glide in Standard Mandarin, i.e., as [lei^{35}] (SM), [lei^{451}] (SM), [lei^{451}] (SM), [lei^{214}] (SM), [nei^{451}] (SM), respectively. This pattern of labiovelar glide retention also occurs in other Southwestern Mandarin varieties, including the Chengdu variety.[6]

Like other Mandarin varieties, Zhongjiang has, in a restricted set of environments, an apical vowel, which we represent as [ɻ̩], e.g., [sɻ̩^{324}] 四 'four'. Since this sound can only occur in syllable nucleus position (preceded by a homorganic consonant), we will discuss it in the vowel section (see also affricate section). In Zhongjiang, we analyze the apical vowel as an allophone of /i/.

Vowels

Monophthongs

There are seven contrastive monophthongs: five oral, non-rhotic vowels, one rhotic vowel, and one nasal vowel. In addition, there is an apical vowel, which we analyze as an allophone of /i/. These eight monophthongs are shown on the chart in Figure 7. The apical vowel, since it is not phonemic in this variety, is shown in square brackets.

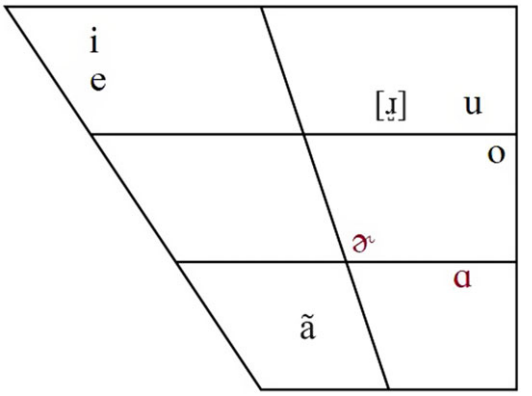

Figure 7. Monophthong vowels.

Vowels:

Open syllables	Closed syllables		
	Before coda /n/	Before coda /ŋ/	
/i/ [ti^{34}] 低 'low'	/in/ [ɕin^{34}] 心 'heart'		/si/ [sɻ̩^{324}] 四 'four' ∗[si]
/ɑ/ [ts^{h}ɑ^{31}] 茶 'tea'		/ɑŋ/ [t^{h}ɑŋ^{31}] 糖 'candy'	
/e/ [pe^{31}] 白 'white'	/en/ [sɐn^{34}] 深 'depth'		

[6] We consider the labio-velar glide a retention from Middle Chinese, which was lost in Standard Mandarin, leading to the synchronic difference.

/u/ [lu^{31}] 绿 ‘green’ ∗lun, c.f., lwɐn

/o/ [ko^{34}] 歌 ‘song’ /oŋ/ [toŋ^{34}] 东 ‘east’

/ɚ/ [ɚ^{324}] 二 ‘two’

/ã/ [lã^{31}] 南 ‘south’

A formant plot of the eight monophthongs, including the non-contrastive apical vowel, is provided in Figure 9. Formants were tracked using the Burg method in Praat. The tokens of the oral, non-rhotic vowels draw from six tokens each, produced in different onset consonant environments but with the same tone [31] ‘falling tone’. This was not possible for the rhotic vowel, which has a more limited distribution (see discussion at the end of pg. 16). The tokens of the nasal vowel draw from the same onset consonant environments as the non-rhotic oral vowels but with more variation in tone. The tokens of the apical vowel as well necessarily draw from its limited distribution (see discussion on pg. 17, first paragraph). A list of the items that went into the formant plot is provided in Appendix B. The mean formant values of each monophthong are labeled with the IPA symbol for the vowel in large font. The individual tokens are shown as the IPA category label in a smaller font that matches the color of the IPA category label for the mean. We used the following eight labels for the monophthongs: /i/, /e/, /u/, /o/, /ɑ/, /ã/,[7] /ɚ/, [ɻ̩]. However, the specific qualities of the vowels each require some additional commentary.

The position of /i/ in the vowel space is high and front. In contrast to Standard Mandarin, we've noticed that the high front vowel in Zhongjiang sometimes triggers aperiodic energy. This is particularly common in the falling tone context.[8]

The position of /e/ in the vowel space is also relatively high, i.e., close to /i/. Another relevant difference between Zhongjiang Mandarin and Standard Mandarin is that Zhongjiang does not have a high front rounded vowel /y/. Additionally, Standard Mandarin has restrictions on the distribution of /e/ that are absent in Zhongjiang. In Standard Mandarin, /e/ generally does not combine with onset consonants, occurring only as an independent syllable in a handful of words, such as the [e^{31}] ‘modal particle’. In Zhongjiang, in contrast, /e/ can occur with onset consonants, e.g., [xe^{31}] 黑 ‘black’, [pe^{31}] 白 ‘white’, [se^{31}] 色 ‘color’.

The high back vowel, /u/, is typically less rounded in Zhongjiang than in Standard Mandarin, and this is reflected in higher F1 and F2. In the formant plot, relative to /o/, /u/ is only slightly higher (lower F1) and is more front (higher H2). We have kept the symbol /u/ to represent this vowel for two reasons. First, even though it is less rounded than /u/ in other language varieties, it is not entirely unrounded. Second, a hyper-articulated token of this vowel involves dynamic formants moving from a more central position in the vowel space towards the high back part of the vowel space, something like [o͡u] or [ə͡u]. These two options suggest that, even though it is more centralized in the vowel plot below, there is a sense in which it is still a high back rounded vowel.

We have noticed that the vowel /u/ can also be produced with turbulent energy in certain environments. These include onsetless syllables, as in /u^{31}/ 吴 ‘a Chinese family name’, and following a labial-dental fricative, e.g., /fu^{31}/ 福 ‘happiness’ (for other examples of vowels

[7] This is a low front vowel, approximating the quality of cardinal vowel 4.

[8] Possibly, the tone context conditions variation in tongue body height for /i/. In Standard Mandarin, tongue body height is also conditioned by tone, but the pattern is a lower tongue body for /i/ in the high tone and falling tone contexts (Shaw et al., 2016). Below, we note that there is an apical vowel allophone of [i] which is also produced with aperiodic energy (see for example, [ts̻^{31}] 汁 ‘juice’), possibly introduced by the preceding fricative/affricate.

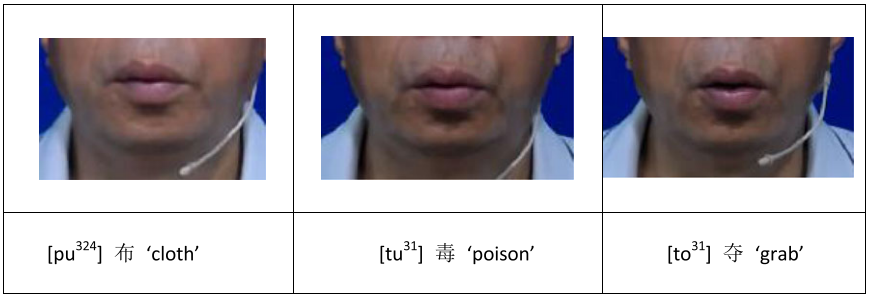

Figure 8. Frontal video of the lips comparing rounding in /u/ and /o/.

produced with turbulent energy, see approximant description). All of these examples also have a falling tone. Our impressionistic observation is that turbulent energy produced with /u/ is also more likely when it is produced with a falling tone.

The quality of /o/ is a mid-back rounded vowel, but it is particularly back in its auditory quality. This auditory quality may be due in part to a high degree of rounding. Figure 8 shows the lips for our speaker during the production of /pu/ (left), /tu/ (middle), and /to/ (right). The figure shows narrow lip aperture for /u/ in both consonantal contexts and greater rounding for /o/.

The low vowel, which we have labeled as /ɑ/ is relatively back (low F2) in these tokens, although more front (higher F2) allophones are also readily observed.

The single contrastive nasal vowel in Zhongjiang is /ã/, which contrasts with /ɑ/ and /e/ in minimal pairs such as: [mã^{324}] 慢 'slow' vs. [mɑ^{324}] 骂 'scold' (c.f., ∗[mãn] vs. ∗[mæn]); [xã^{31}] 含 'contain' vs. [xe^{31}] 黑 'black'. The nasal vowel developed from loss of alveolar nasal codas in the environment of /ɑ/. Consequently, /ɑ/ is no longer followed by an alveolar nasal—it can still be followed by a velar nasal—and, /ã/ can only occur in open syllables.

Nasal codas condition other patterns of vowel allophony as well. In the environment of the alveolar nasal coda, neither [u] nor [e] appears. Instead there is a centralized and lowered allophone in this environment, e.g., [sɐn^{34}] 深 'depth'. At first blush, it might seem reasonable to consider that this surface vowel [ɐ] found before alveolar nasals derives from either /u/ or /e/ phonemes. Historically, some of the words produced with [ɐn] rimes derive from ∗e and some derive from ∗wɐ. As we noted above, nasals do not follow /u/ in Zhongjiang, so it seems more likely that [ɐ] is a surface realization of /e/. If this is the case, the nasal coda conditions lowering and centralization of /e/ to [ɐ], such that [sɐn^{34}] 深 'depth' derives from /sen^{34}/. Relatedly, [ɐ] also occurs as the first member of a diphthong [ɐɯ], which could be analyzed as /eu/.

Of the five non-rhotic oral vowels, there is a four-way contrast before nasal codas. If we adopt the analysis of [ɐ] as deriving from /e/, then the four monophthongs that contrast before nasals are: /i/, /e/, /o/, /ɑ/. On this analysis, /u/ cannot be followed by a nasal.

The contrastive rhotic vowel is /ɚ/. This vowel typically occurs in syllables that lack onset and coda consonants, as in [ɚ^{31}] 儿 'son', [ɚ^{51}] 耳 'ear' and [ɚ^{324}] 二 'two'. The other monophthongs can all also occur in such syllables, which make a seven-way contrast between syllables consisting only of a monophthong: /ɚ/ [ɚ] vs. /e/ [e] vs. /o/ [o] vs. /a/ [ɑ] vs. /ã/ [ã] vs. /i/ [j] vs. /u/.[v].

The rhotic vowel can also occur in syllables with an onset consonant if derived through contraction, a common process in Mandarin varieties, referred to as *Er-hua.* For example, surface syllables such as [t^{h}ɚ^{34}], which have an onset consonant and a rhotic vowel, derive from contraction of an open syllable /t^{h}eu^{31}/ [t^{h}ɐɯ^{31}] and /ɚ^{31}/, so that /se^{31} t^{h}eu^{31} ɚ^{31}/ 'tongue' surfaces as [se^{31} t^{h}ɚ^{34}] 舌头 'tongue'. In this contraction process, the vowel in the

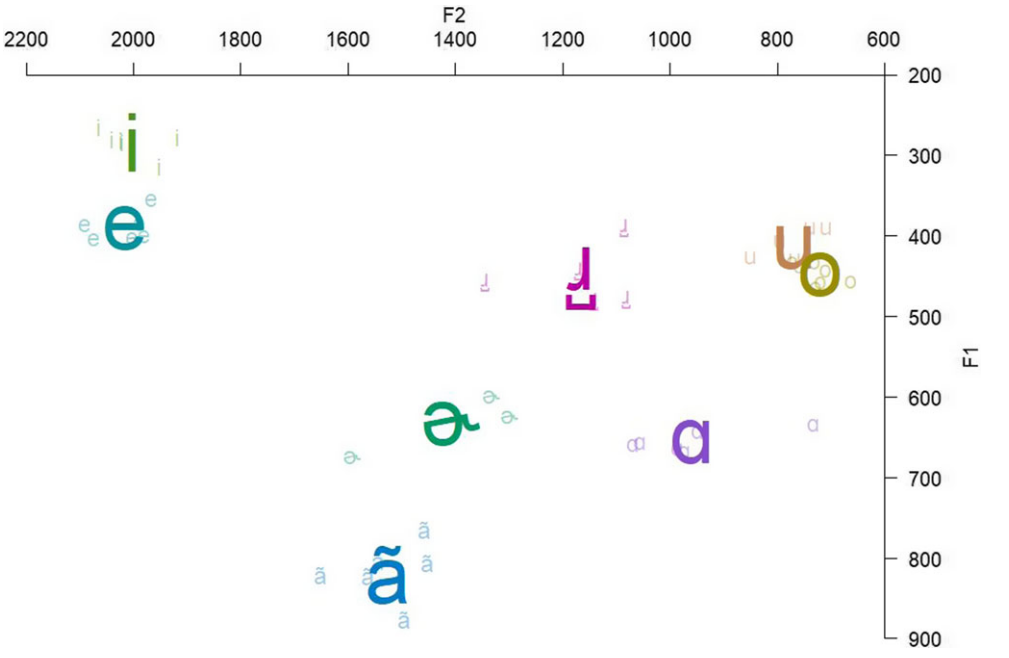

Figure 9. F1 and F2 values of monophthongs produced in open syllables by Sp1 and Sp2.

syllable preceding a rhotic vowel is replaced with the rhotic vowel, resulting in syllables that, on the surface, have both an onset consonant and a rhotic vowel.

Zhongjiang does have an apical vowel, [ɻ̩]. This vowel surfaces as an allophone of /i/ after /s/, /z/, /ts/, /ts^{h}/ (see sections on fricatives, pg. 10, and affricates, pg. 5). In Standard Mandarin, when [ɻ̩] follows [ts ts^{h} s], it is typically referred to as a syllabic apico-laminal or as a laminal denti-alveolar approximant. Both of these fall under the cover term of 'apical vowels' and occur only in open syllables in Standard Mandarin (Duanmu, 2007:111). Zhongjiang shares this same distribution. [ɻ̩], as an allophone of /i/, occurs only in open syllables. The formants of the apical vowel allophone are more centralized than /i/. In the examples included in this article, there is an average F1 of 449 Hz, which is closer to /e/ than to /i/; the average F2 is 1165 Hz, which is between /i/ and /u/. The presence of aperiodic energy is also a dimension that varies across Chinese varieties (e.g., Ling, 2009; Faytak & Lin, 2015; Shao & Ridouane, 2023). In two of the examples included with this illustration [sɻ̩^{34}] 丝 'silk' and [zɻ̩^{31}] 日 'sun', there is clearly aperiodic energy throughout the apical vowel.

A final note about monophthongs, unlike Standard Mandarin, there is no /y/ in Zhongjiang Chinese. All the /y/ in Mandarin Chinese are pronounced as /i/ in Zhongjiang Chinese. Thus, /ji^{31}/ ㇐ 'one' has the same pronunciation as 鱼 'fish' in Zhongjiang, c.f., a /i/∼/y/ contrast in Standard Mandarin.

Diphthongs

There are four contrastive diphthongs. Phonemically, we characterize these as starting with a mid- /e/ or low- /ɑ/ vowel and ending with an offglide, either /i/ or /u/: /ɑi/, /ei/, /ɑu/, /eu/. However, the offglide portion of /ɑu/ and /eu/ is almost entirely unrounded. Additionally, the starting position of /e/ is quite central and low, more like [ɐ], a quality that is also seen

before alveolar nasals: [sɐ̲n^{34}] 深 ‘depth’. Phonetically, /au/ and /eu/ are better characterized as [ɑɯ] and [ɐɯ], respectively.

Diphthongs:

/ɑi/ [k^{h}ai^{34}] 开 ‘to open’

/ei/ [p^{h}ei^{31}] 赔 ‘to pay’

/ɑu/ [pɑɯ^{451}] 宝 ‘treasure’

/eu/ [t^{h}ɐɯ^{451}]抖 ‘shake’

A formant plot of the four diphthongs is provided in Figure 10. The figure plots the F1 and F2 of the representative tokens for each diphthong at three time points, 25%, 50%, and 75% of total vowel duration.

In addition to the four diphthongs above, which can be characterized as off-gliding diphthongs, the high front vowels, /i/ and /u/, can proceed some other vowels, giving rise to on-gliding. The distributional restrictions, i.e., which vowels can follow /i/ and /u/, are described in the approximants section (Table 4).

Nasal onset consonants appear to condition some variation in diphthongs. In words beginning with /m/, the Zhongjiang diphthong /eu/ often corresponds to the Standard Mandarin diphthong /au/ or /u/. For example, /meu^{324}/ [mɐɯ^{324}] 茂 ‘luxuriant’ 贸 ‘trade’ in Zhongjiang is produced as [mau^{51}] (SM) in Standard Mandarin. These words are different still in the Chengdu variety of Mandarin, produced as [moŋ^{324}]. These variants have in common a tongue dorsum rising movement but they differ in the vertical extent of the movement, i.e., starting and ending points of the movement, and whether it co-occurs with rounding (Standard Mandarin) or nasalization (Chengdu Mandarin). Notably,

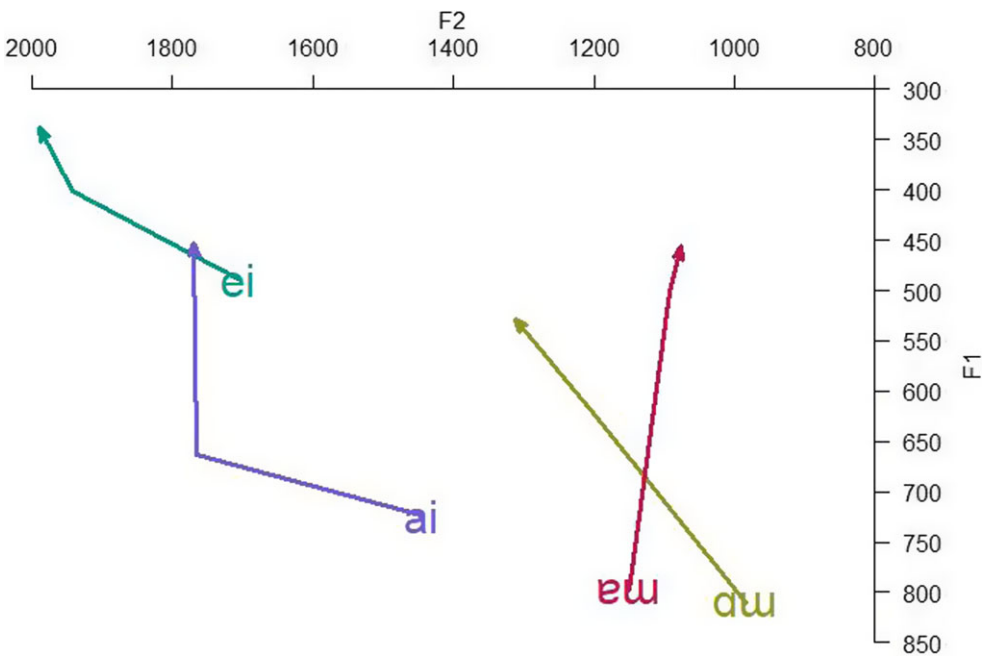

Figure 10. Formant tracks of diphthongs. F1 and F2 are plotted at 25%, 50%, and 75% of total duration.

in non-nasal environments many words maintain the same diphthong across varieties. For example, /xɐu^{324}/ [xɐɯ^{324}] 后 'back' in Zhongjiang is produced as [xɐu^{51}] (SM) in Standard Mandarin, /kau^{34}/ [kɑɯ^{34}] (ZC) 高 'high' in Zhongjiang is produced as [kau^{55}] (SM) in Standard Mandarin. Possibly co-articulation with the initial nasal complicates the perception of vowel height by widening first formant bandwidth (e.g., Carignan, 2018), conditioning variation across varieties. This diphthong variation is primarily observed in the /m/ environment—the nasal consonant that occurs in onset position in both varieties (see section on nasals, pg. 6).

Tones

Citation form

There are four contrastive tones in Zhongjiang: high-rising (T1), middle falling (T2), high falling (T3), fall-rise (T4). Each tone is exemplified below, along with Chao numerals representing the pitch contour:

T1 High rising	/u^{34}/ 乌 'dark'
T2 Middle falling	/u^{31}/ 屋 'room'
T3 High falling	/u^{451}/ 五 'five'
T4 Fall-rise	/u^{324}/ 雾 'fog'

The labels T1–T4 have correspondences with tones in other varieties, including Standard Mandarin. That is, the syllables with T1, a high rising pitch contour in Zhongjiang, also pattern together in Standard Mandarin, where these syllables have a high flat contour, /55/. The same goes for T2, T3, T4. In this sense, the tone labels T1–T4 function to describe large

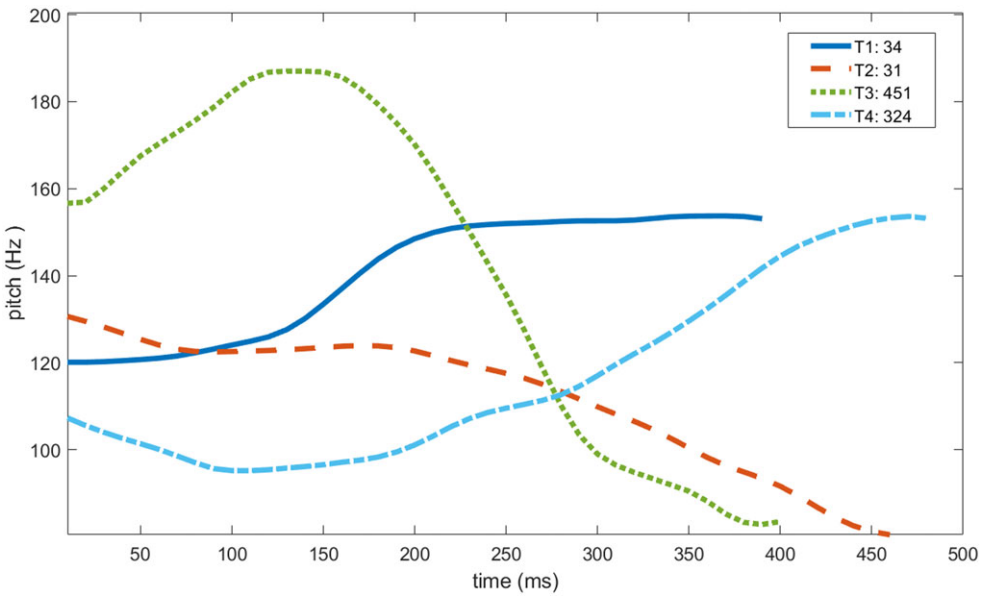

Figure 11. Example pitch tracks for each tone.

swathes of the lexicon that pattern together in tone across Mandarin varieties, even as the phonetic realization of the tone category varies.

Pitch tracks of the four citation tones are shown in Figure 11. We characterize T1 as 'middle-rising', 34 in Chao numerals, which is consistent with past work on related Southwest Mandarin varieties. T2, we characterize as a middle falling tone, 31. T3 is a high falling tone. Oftentimes, there is an initial rise to the high before falling. This pattern is reflected in the pitch track in Figure 11. Lastly, T4 is a fall rise tone, 324. In the pitch track below, the end of the pitch contour reaches the level of the end of T1. Outside of single syllable citation form pronunciation, the pitch rise of T4 typically does not reach the height of T1; rather, it is realized as low tone, 32, only.

Tone sandhi

Some words of Zhongjiang, like other dialects of Mandarin, involve fully reduplicated syllables. In these words, T2, T3, and T4 undergo tone sandhi. As summarized in Table 5, T2 becomes T1 on the second of two identical syllables; T3 becomes T2; and T4 becomes T1. For completeness, we also provide an example of T1 reduplication. The second of two identical syllables with T1 does not undergo a shift in tonal category—it remains T1; however, the realization of T1 in the second syllable can be higher and flatter than the realization of T1 on the first syllable. This reflects a broader trend in Zhongjiang, whereby the second syllable of disyllabic words tends to be more prominent than the first, c.f., the opposite trend in Standard Mandarin, whereby the second syllable is sometimes reduced relative to the first (Duanmu, 2007; Qu, 2013).

A different set of tone sandhi patterns is found outside of syllable reduplication. However, there are exceptions to many of the patterns. For example, T1 + T3 syllables sometimes surface as T1 + T2, e.g., [$t^hi^{34}ts\underset{\sim}{ɻ}^{31}$] 梯子 'ladder'. But there are also examples of T1+ T3 compounds that do not undergo sandhi, e.g., [$k^hai^{34}swei^{451}$] 开水 'boiled water'. Exactly what conditions the variation in tone sandhi—possibly metrical stress, morpho-syntactic, or lexical factors—requires future research. One type of example suggesting a basis in the morpho-syntax or related phonological properties such as metrical stress involves N-V dyads. For example, the compound 热水 [ze^{324} $swei^{451}$] is ambiguous between a noun 'hot water' and a verb 'to heat water'. The compound is a combination of T4 and T3 syllables, which undergo tone Sandhi, surfacing as T4 + T2, only for the noun meaning 'hot water'. The verb meaning resists Sandhi, which means it is still T4 + T3 for the verb meaning 'to heat the water'.

Table 5. Tone sandhi patterns in fully reduplicated syllables

Sandhi pattern	Examples
T1+T1→ T1 'high-rise'+T1 'high-level'	[fei^{34} fei^{45}] 灰灰 'dirt' [$jã^{34}$ $jã^{45}$] 烟烟 'smog'
T2+T2→T2 'mid-fall' +T1 'high-rise'	[$ko^{31}ko^{34}$] 角角 'corner' [$p^ho^{31}p^ho^{34}$] 婆婆 'grandma'
T3+T3→T1 'high-fall'+T2 'mid-fall'	[$ts^haɯ^{45}ts^haɯ^{31}$] 草草 'grass' [$saɯ^{45}saɯ^{31}$] 嫂嫂 'sister in law'
T4 +T4→T4 'low'+T1 'high-rise'	[$toŋ^{32}toŋ^{34}$] 洞洞 'hole' [$foŋ^{32}xoŋ^{34}$] 缝缝 'crack'

Table 6. Tone sandhi patterns and exceptions

	Sandhi	T1 (34)	T2 (31)	T3 (451)	T4 (324)
T1 (34)	Pattern	**No sandhi**	**No sandhi**	T1(34)+T2(31)	T1(34) + T2(31)
	Example			[$t^hi^{34}ts\underline{ɿ}^{31}$] 梯子 'ladder'	[$t^hiã^{34}$ $ɕ^hi^{31}$] 梯子 'weather'
	Exception			[$twã^{34}$ wu^{451}] 天气 'dragon boat festival'	[$t^hiã^{34}$ $liaŋ^{324}$] 端午 'dawn'
T2 (31)	Pattern	**No sandhi**	T2(31)+T1(34)	T2(31)+T1(34)	T2(33)+T1(34)
	Example		[$tɕ^hã^{31}t^hɐɯ^{34}$] 天亮 'front'	[$ts^hɐn^{31}l^di^{34}$] 前头 'city'	[$je^{33}l^diaŋ^{34}$] 城里 'moon' [$xo^{33}ŋ^gã^{334}$] 月亮 'river bank' [$xwaŋ^{33}l^di^{324}$] 月亮 'calendar'
	Exception		[$xe^{31}t^haɯ^{31}$] 河岸 'walnut' [mei^{31} $jɐɯ^{31}$] 核桃 'kerosene'	[$ɲ^jjã^{31}ti^{451}$] 黄历 'the end of a year' [$l^djaŋ^{31}swei^{451}$] 年底 'cold water'	
T3 (451)	Pattern1	**No sandhi**	T1(45)+T1(34)	T1(45)+T2(31) T1(45)+T1(34)	T1(45)+T2(31)
	Example		[$ts^hwã^{45}lai^{34}$] 煤油 'turn back'	[$saɯ^{45}$ wu^{31}] 凉水 'noon' [$ma^{45}ɲ^ji^{34}$]晌午 'ant'	[$l^djɐɯ^{45}su^{31}$] 转来 'willow'
	Exception		[$ji^{45}ɕ^hã^{31}$] 柳树 'before' [$tsaɯ^{45}sɐn^{31}$] 以前 'morning'	[$xo^{45}sã^{451}$]蚂蚁 'lightning'	
T4 (324)	Pattern1	T4(32)+T1(34)	T4(32)+T1(34)	T4(32)+T3(451)	T4(32)+T1(34) T4(32)+T2(31)
	Example	[$xɐɯ^{32}t^hjã^{34}$] 后天 'the day after tomorrow' [$jɐɯ^{32}pjã^{34}$] 右边 'right side'	[$t^hai^{32}jaŋ^{34}$] 太阳 'sun'	[$ɕa^{32}ji^{451}$] 下雨 'to rain'	[$tɕin^{32}tɕ^hi^{34}$] 进去 'come in' [$ɕã^{32}tsai^{31}$]现在 'now'
	Exception		[$jã^{324}t^haŋ^{31}$]堰塘 'pond' [$ɕa^{324}t^hɐɯ^{31}$]下头 'below'		

Table 6 lists examples of various Sandhi patterns as well as some known exceptions to each pattern.[9] The table focuses on cases that involve a categorical shift in tone. There are also some cases of within-category phonetic variation, such as T1 + T1 combinations,

[9] Listed exceptions are cases for which we have a recording that resists the tone sandhi pattern described in the table. In some cases, we do not have any recordings of an exception within our corpus of 1200 recorded words. These 'exception' cells are left blank in the table. However, this does not necessarily mean that these tone sandhi patterns are entirely exceptionless. A larger corpus may reveal some exceptions to these patterns as well.

which sometimes surface with a high-level tone for the second T1, e.g, [ɕɑŋ^{34} ku^{45}] 香菇 'mushroom', [fa^{34}sɐn^{45}] 花生 'peanut', the same phonetic pattern described above for reduplicated T1 syllables.

Syllable structure and phonotactics

The syllable structure in Zhongjiang Chinese is (C)(G)V(C), where C stands for consonant, G stands for glide, V stands for vowel. We have already reported some phonotactic restrictions on consonant and vowel combinations (see Table 4 for coronal consonants and Table 8 for glides). All consonants can be in the onset except [n]. Glides [j]/[w] can also be a syllable onset, such as [wai^{324}] 外 'outside', [je^{214}] 夜 'night'. The rhotic vowel [ɚ] cannot be immediately preceded by a consonant, except through contraction. It can occur independently, in vowel-initial syllables, as in [ɚ^{31}] 儿 'son' or it can follow other vowels, creating complex syllable nuclei (see, e.g., Lee & Zee, 2003). For consonant codas, only [n] and [ŋ] can be codas, as in [ɕin^{34}] 心 'heart', [t^{h}aŋ^{31}] 糖 'candy'. There are also some restrictions on consonant-glide combinations. For example, the glide [w] cannot follow the bilabial stops: [p], [p^{h}], [m] (see also the descriptions of approximants on pg. 12–13).

Recorded passage

The IPA transcription below is a phonemic transcription of the North Wind and the Sun passage, translated into Zhongjiang Chinese. The Chinese orthography is given below the phonemic transcription. The phonemic transcription denotes the lexical tone of each syllable, as opposed to the surface tone resulting from tone sandhi. For example, the sequence of two T4 tones in tse^{324} (T4) ko^{324} (T4) undergoes tone sandhi, and is produced as T4–T1, tse^{32} (T4) ko^{34} (T1), by the speaker of the passage. Our transcription denotes the underlying tones, e.g., tse^{324} (T4) ko^{324} (T4), throughout. Following the Chinese Orthography we provide a table aligning the IPA, English gloss, and Chinese characters.

IPA transcription

pe^{31} foŋ^{34} xo^{31} | t^{h}ai^{324} jɑŋ^{31} | sɻ̩^{324} xɑɯ^{451} p^{h}oŋ^{31} jɐɯ^{451} || ji^{31} t^{h}jã^{34} | t^{h}ɑ^{34} m^{b}ɐn^{31} tsai^{324} ji^{31} tɕ^{h}i^{451} | tsɐn^{34} lɐn^{324} | k^{h}ã^{324} lɑ^{451} ko^{31} lɐn^{31} kã^{324} ɕi^{34} || ts^{h}ɐn^{34}ko^{324} tɕ^{h}i^{324} | ts^{h}ɐn^{34} ko^{324} lai^{31} ŋ^{g}ã^{34} | m^{b}o^{324} te^{31} ko^{324} so^{451} ji^{451} zã^{31} || tse^{324} ko^{324} sɻ̩^{31} xɐɯ^{324} | jɐɯ^{451} ko^{324} ko^{324} lu^{324} ti^{31} zɐn^{31} | lai^{31} lo^{31} | pe^{31} foŋ^{34} ŋ^{g}ã^{34} | tɕɐɯ^{324} twei^{324} t^{h}ai^{324} jɑŋ^{31} so^{31} | ŋ^{g}o^{451} m^{b}ɐn^{31} k^{h}ã^{31} | lɑ^{451} ko^{324} | lɐn^{31} pɑ^{451} lɑ^{324} ko^{324} | ko^{324} lu^{324} ti^{31} zɐn^{31} | ji^{34} fu^{31} | t^{h}o^{31} te^{31} ɕɑ^{324} lai^{31} | ŋ^{g}o^{451} m^{b}ɐn^{31} | tɕɐɯ^{324} so^{31} lɑ^{451} ko^{31} | lɐn^{31} kã^{324} || t^{h}ai^{324} jɑŋ^{31} | t^{h}oŋ^{31} ji^{324} lɐ^{31} | pe^{31} xoŋ^{34} tɕɐɯ^{324} ɕã^{34} tɕ^{h}i^{324} | twei^{324} tso^{31} lɑ^{324} ko^{324} | ko^{324} lu^{324} ti^{31} zɐn^{31} ʂɻ̩^{451} tɕin^{324} ji^{31} ts^{h}wei^{34} | lɑ^{324} ko^{324} zɐn^{31} ã^{34} | pɑ^{324} ji^{34} fu^{31} | ts^{h}ɑɯ^{34} to^{31} | je^{31} ts^{h}ɑɯ^{34} je^{31} tɕin^{451} | ts^{h}wei^{34} te^{31} je^{31} tɑ^{324} ts^{h}ɑɯ^{34} to^{31} je^{31} tɕin^{451} | pɑ^{451} pe^{31} foŋ^{34} ɑ^{31} | tɕ^{h}i^{324} fai^{324} lɐ^{31} || t^{h}ai^{324} jɑŋ^{31} ã^{34} | tsai^{324} ji^{31} pjã^{34} | in^{34} to^{31} ɕɑɯ^{324} || t^{h}ɑ^{34} tɕɐɯ^{324} twei^{324} tʂe^{324} ko^{324} pe^{31} foŋ^{34} so^{31} | k^{h}ã^{324} ŋ^{g}o^{451} ti^{31} || t^{h}ai^{324} jɑŋ^{31} tɕɐɯ^{324} tsɐɯ^{451} tɕ^{h}i^{324} | twei^{324} tso^{31} tʂe^{324} ko^{324} zɐn^{31} | tsɑɯ^{324} tso^{31} | tse^{324} ko^{324} zɐn^{31} | pɑ^{451} t^{h}ai^{324} jɑŋ^{31} | tsã^{451} tɕin^{324} lo^{31} ji^{31} tsɑɯ^{324} | tʂe^{324} ko^{324} zɐn^{31} ŋ^{g}ã^{34} | ze^{31} te^{31} pu^{31} ɕin^{31} ɐn^{31} | ze^{31} te^{31} m^{b}o^{31} fɑ^{31} | pɑ^{451} ji^{34} fu^{31} | tɐɯ^{34} tɑ^{451} sɻ̩^{31} lo^{31} || tswei^{324} xɐɯ^{324} | pɑ^{451} ji^{34} fu^{31} ŋ^{g}ã^{34} | je^{451} tɕɐɯ^{324} t^{h}o^{31} to^{31} | kã^{34} kã^{44} tɕin^{324} tɕin^{324} || pe^{31} xoŋ^{34} ŋ^{g}ã^{34} | pu^{31} te^{31} | pu^{31} so^{31} | xai^{31} sɻ̩^{324} t^{h}ai^{324} jɑŋ^{31} | ɲ^{j}i^{451} lɐn^{31} kã^{324} ɕi^{34} ||

Chinese Orthography

北风和太阳是好朋友。一天，他们在一起争论，看哪个能干些。争过去争过来咬莫得个所以然。这个时候，有个过路的人来了。北风咬就对太阳说：“我们看哪个能把这个过路的人衣服脱得下来，我们就说哪个能干。”太阳同意了，北风就先去对着那个过路的人，使劲一吹。那个人咬，把衣服操到，越操越紧，吹得越大，操得越紧，把北风啊气坏了。太阳啊在一边阴到笑。他就对这个北风说：“看我的!”太阳就走去，对着这个嗯，照着这个人，把太阳攒劲了一照，这个人咬热得不行啊，热到莫法，把衣服都打湿了。最后把衣服咬也就脱到干干净净。北风咬，“不得不说，还是太阳你能干些。”

Alignment of IPA, English gloss and Chinese character

pe^{31} foŋ^{34}	xo^{31}	tʰai^{324} jɑŋ^{31}	sɻ^{324}	xɑɯ^{451}	pʰoŋ^{31}jɐɯ^{451}
North wind	and	sun	COP	good	friend
北风	和	太阳	是	好	朋友

‘The north wind and the sun are good friends.’

ji^{31} tʰjã^{34}	tʰɑ^{34} mᵇɐn^{31}	tsai^{324}	ji^{31} tɕʰi^{451}	tsɐn^{34}	lɐn^{324}	kʰã^{324}	lɑ^{451} ko^{31}	lən^{31}kã^{324}	ɕi^{34}
One day	3pPL	PREP	together	argue		see	which one	powerful	more
一天	他们	在	一起	争论		看	哪个	能干	些

‘One day, they debated together to see which one had the stronger capability.’

tsʰɐn^{34}	ko^{324} ɕʰi^{324}	tsʰɐn^{34}	ko^{324} lai^{31}	ŋᵍã^{34}	mᵇo^{324}	te^{31} ko^{32}	so^{451} ji^{451} zã^{31}
Argue	DV	argue	DV	MOD	NEG		result
争	过去	争	过来	咬	莫得个		所以然

‘They argued and argued, but no result.’

tse^{324} ko^{324}	sɻ^{31} xɐɯ^{324}	jɐɯ^{451}	ko^{324}	ko^{324} lu^{324} ti^{31} zɐn^{31}		lai^{31}	lo^{31}
This	time	have	CLASS	passer-by		come	PER
这个	时候	有	个	过路的人		来	了

‘At this time, a passer-by came.’

pe^{31} foŋ^{34}	ŋ^{g}ã^{34}	ɕɐɯ^{324}	twei^{324}	t^{h}ai^{324} jɑŋ^{31}	so^{31}
north wind	MOD	adverb	PREP	sun	say
北风	哎	就	对	太阳	说

ŋ^{g}o^{451} m^{b}ɐn^{31}	k^{h}ã^{31}	lɑ^{451} ko^{324}	lɐn^{31}	pɑ^{324}
1pPL	see	who	can	PREP
我们	看	哪个	能	把

tse^{324} ko^{324}	ko^{324}lu^{324} ti^{31} zɐn^{31}	ji^{34} fu^{31}	t^{h}o^{31} te^{31}	ɕɑ^{324} lai^{31}
This	passer-by	clothes	take off-LINK	DV
这个	过路的人	衣服	脱得	下来

ŋ^{g}o^{451} m^{b}ɐn^{31}	ɕɐɯ^{324}	so^{31}	lɑ^{451} ko^{31}	lən^{31} kã^{324}
3pPL	adverb	say	which one	capable
我们	就	说	哪个	能干

t^{h}ai^{324} jɑŋ^{31}	t^{h}oŋ^{31} ji^{324}	lɐ^{31}
sun	agree	PER
太阳	同意	了

'Then the north wind said to the sun: Let's see which one can take off the clothes of this passer-by, and we would say which one is more capable. The sun agreed.'

pe^{31} xox^{3}	tɕɐɯ^{324}	ɕã^{34} tɕ^{h}i^{324}	twei^{324} tso^{31}	lɑ^{324} ko^{324}	ko^{324}lu^{324} ti^{31} zɐn^{31}
north wind	adverb	go first	PREP	that	passer-by
北风	就	先去	对着	那个	过路的人

sɻ^{451} tɕin^{324}	ji^{31} ts^{h}wei^{34}
strongly	blow
使劲	一吹

'The north wind went to the passer-by first and blew hard.'

lɑ^{324}	ko^{324}	zɐn^{31}	ã^{34}	pɑ^{324}	ji^{34} fu^{31}	ts^{h}ɑɯ^{34} to^{31}
that		person	MOD	PREP	clothes	swap
那个		人	哎	把	衣服	操到

je^{31} ts^{h}ɑɯ^{34}	je^{31} tɕin^{451}	ts^{h}wei^{34} te^{31}	je^{31} tɑ^{324}	ts^{h}ɑɯ^{34} to^{31}	je^{31} tɕin^{451}
wrap	tight	blow-LINK	stronger	wrap	tighter
越操	越紧	吹得	越大	操得	越紧

pɑ^{451}	pe^{31} foŋ^{34}	ɑ^{31}	tɕ^{h}i^{324}	fai^{324}	lɐ^{31}
PREP	north wind	MOD	displease	strongly	PER
把	北风	啊	气	坏	了

'The man wrapped his clothes tightly. The stronger the wind blew, the tighter he wrapped himself. This situation displeased the north wind as the man wrapped his clothes tightly.'

t^{h}ai^{324} jɑŋ^{31}	ã^{34}	tsai^{324}	ji^{31} pjã^{34}	in^{34} to^{31} ɕɑɯ^{324}
the sun	MOD	PREP	the side	chuckle
太阳	哎	在	一边	阴到笑

'The sun chuckled mischievously.'

t^{h}ɑ^{34}	tɕɐɯ^{324}	twei^{324}	tɕe^{324} ko^{324}	pe^{31} foŋ^{34}	so^{31}	k^{h}ã^{324}	ŋ^{g}o^{451} ti^{31}
3pS	adverb	PREP	this	north wind	say	see	1PS-REL
他	就	对	这个	北风	说	看	我的

'Next, it said to this north wind, See carefully what I would do!'

t^{h}ai^{324} jɑŋ^{31}	tɕɐɯ^{324}	tsɐɯ^{451} tɕ^{h}i^{324}	twei^{324} tso^{31}	tʂe^{324} ko^{324}	ɐn^{31}
the sun	adverb	walk to	PREP	this	MOD
太阳	就	走去	对着	这个	嗯

tsɑɯ^{324} tso^{31}	tse^{324} ko^{324}	zɐn^{31}	pɑ^{451}	t^{h}ai^{324} jɑŋ^{31}	tsã^{451} tɕin^{324}	lo^{31}	ji^{31} tsɑɯ^{324}
shine	this	person	PREP	the sun	hard	PER	shine
照着	这个	人	把	太阳	攒劲	了	一照

'The sun went over and shone on this man.'

tɕe^{324}	ko^{324}	zɐn^{31}	ŋ^{g}ã ^{34}	ze^{31} te^{31}	pu^{31} ɕin^{31}	ɐn^{31}	ze^{31} te^{31}	m^{b}o^{31} fɑ^{31}
this person			MOD	hot-LINK	so much	MOD	hot-LINK	so much
这个人			哈	热 得	不行	嗯	热 得	莫法

pɑ^{451}	ji^{34} fu^{1}	tɐɯ^{34}	tɑ^{451} sɻ̩^{31}	lo^{31}
PREP	clothes	all	to wet	PER
把	衣服	都	打湿	了

'The man was so hot that sweat wetted his clothes.'

tswei^{324}	xɐɯ^{324}	pɑ^{451}	ji^{34} fu^{31}	ŋ^{g}ã^{34}	je^{451} tɕɐɯ^{324}	t^{h}o^{31} to^{31}	kã^{34}kã^{44}tɕin^{324}tɕin^{324}
finally		PREP	clothes	MOD	also	take off	clean
最后		把	衣服	哈	也就	脱到	干干净净

'Finally, he took off all of his clothes.'

pe^{31}	xoŋ^{34}	ŋ^{g}ã^{3}	pu^{31} te^{31} pu^{31}	so^{31}	xai^{31} sɻ̩^{324}	t^{h}ai^{324}	jɑŋ^{31}	ɲ^{j}i^{451}	lɐn^{31} kã^{324} ɕi^{34}
north wind	MOD	have to		say	still	sun		2pS	more capable
北风	哈	不得不		说	还是	太阳		你	能干些

'The north wind had to say, Sun, you are the stronger one.'

Glossary

1pS – 1st person singular pronoun
2pS – 2nd person singular pronoun
3pS –3rd person singular pronoun
1pPL –1st person plural pronoun
3pPL – 3rd person plural pronoun
CLASS – classifier
COP – copular verb
DV – directional verb
LINK – linking particle
MOD – modal particular
NEG – negation marker
REL – relative clause marker
PER – perfective marker
PREP – preposition

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Appendix A. List of items that contributed to the measurements of VOT for aspirated and unaspirated plosives reported in Table 1

[pɑ^{451}] 把 'handle', [pɑ^{34}] 爬 'climb', [pu^{324}] 布 'cloth', [po^{31}] 簿 'blotter', [pu^{324}] 步 'step', [pei^{324}] 贝 'shell', [pai^{324}] 拜 'bye', [pai^{451}] 摆 'put', [pai^{324}] 败 'fail', [pi^{324}] 币 'coin', [pei^{34}] 杯 'cup', [pei^{324}] 背 'back', [pei^{34}] 碑 'stele', [pei^{324}] 被 'blanket', [pi^{451}] 比 'compare to', [pi^{31}] 鼻 'nose', [pɑɯ^{451}] 宝 'treasure', [pɑɯ^{324}] 抱 'hug', [pɑɯ^{34}] 包 'bag', [pɑɯ^{451}] 饱 'full', [pjɑɯ^{451}] 表 'watch', [pã^{324}] 扮 'dress up', [pã^{324}] 办 'do', [pɑ^{31}] 八 'eight', [pã^{34}] 班 'class', [pã^{451}] 板 'board', [pjã^{324}] 变 'turn', [pjã^{324}] 便 'convenience', [pje^{31}] 别 'do not', [pjã^{451}] 扁 'flat', [pje^{34}] 憋 'hold', [pã^{34}] 搬 'move', [pã^{324}] 半 'half', [po^{31}] 拨 'to pull', [pi^{31}] 笔 'pen', [pɐn^{451}] 本 'notebook', [pjɑŋ^{34}] 帮 'help', [po^{31}] 薄 'thin', [po^{31}] 缚 'bind', [pɑŋ^{451}] 绑 'tie', [pɑŋ^{324}] 棒 'stick', [po^{31}] 剥 'peel', [pe^{451}] 北 'north', [pin^{34}] 冰 'ice', [pje^{34}] 逼 'force', [pe^{31}] 百 'hundred', [pe^{31}]白 'white', [pin^{34}] 兵 'soldier', [pin^{451}] 柄 'handle', [pin^{324}] 病 'illness', [pin^{451}] 饼 'pancake', [pi^{31}] 壁 'wall', [p^{h}o^{324}] 破 'broken', [p^{h}o^{31}] 婆 'grandmother', [p^{h}u^{451}] 谱 'spectrum', [p^{h}u^{34}] 铺 'pave', [p^{h}ai^{31}] 排 'row', [p^{h}ai^{324}] 派 'delivery', [p^{h}ai^{31}] 牌 'card', [p^{h}ei^{324}] 配 'match', [p^{h}ei^{31}] 赔 'compensate', [p^{h}i^{31}] 皮 'skin', [p^{h}i^{324}] 屁 'fart', [p^{h}ɑɯ^{324}] 炮 'cannon', [p^{h}jɑɯ^{324}] 票 'ticket', [p^{h}in^{451}] 品 'sample', [p^{h}jã^{324}] 骗 'cheat', [p^{h}jã^{324}] 片 'piece', [p^{h}ã^{324}] 判 'judge', [p^{h}ã^{31}] 盘 judge', [p^{h}o^{31}] 泼 'spill', [p^{h}in^{31}] 贫 'poor', [p^{h}i^{31}] 匹 'be equal to', [p^{h}ɐn^{31}] 盆 'basin', [p^{h}ɑŋ^{324}] 胖 'fat', [p^{h}oŋ^{31}] 朋 'friend', [p^{h}e^{31}] 拍 'pat', [p^{h}oŋ^{31}] 棚 'shack', [p^{h}in^{31}] 平 'flat', [p^{h}in^{31}] 瓶 'bottle', [p^{h}i^{31}] 劈 'rive', [p^{h}oŋ^{31}] 蓬 'fluffy', [to^{34}] 多 'many', [tɑ^{324}] 大 'big', [to^{451}] 躲 'hide', [tu^{451}] 赌 'bet', [tu^{324}] 杜 'a last name', [tai^{324}] 袋 'bag', [tai^{324}] 带 'bring', [ti^{34}] 低 'low', [ti^{324}] 弟 'younger brother', [ti^{324}] 递 'pass', [twei^{324}] 对 'for or to', [ti^{324}] 地 'ground', [tɑɯ^{34}] 刀 'knife', [tɑɯ^{324}] 道 'way', [tjɑɯ^{324}] 钓 'fish', [tɐɯ^{324}] 豆 'bean', [tjɐɯ^{34}] 丢 'lose', [tɑ^{31}] 搭 'build', [tã^{451}] 胆 'courage', [tã^{324}] 淡 'light', [tjæ^{451}] 点 'spot', [tjæ^{324}] 店 'store', [tje^{31}] 跌 'tumble', [tje^{31}] 碟 'dish', [tæ^{34}] 单 'single', [tɑ^{31}] 达 'reach', [tjã^{451}] 典 'law', [tjã^{324}] 垫 'pad', [twã^{34}] 端 'hold', [twã^{451}] 短 'short', [twã^{324}] 断 'break', [to^{31}] 夺 'deprive', [twɐn^{34}] 墩 'block', [tɐn^{34}] 蹲 'crouch', [tɑŋ^{451}] 党 'Party', [tɐn^{34}] 灯 'light', [tɐn^{451}] 等 'wait', [tɐn^{324}] 凳 'chair', [te^{31}] 得 'get', [tɑ^{451}] 打 'fight', [tin^{34}] 钉 'nail', [tin^{451}] 顶 'top', [tin^{324}] 定 'fix', [ti^{31}] 笛 'flute', [toŋ^{34}] 东 'east', [toŋ^{451}] 懂 'understand', [toŋ^{324}] 冻 'freeze', [toŋ^{324}] 动 'move', [toŋ^{324}] 洞 'hole', [tu^{31}] 读 'read', [toŋ^{34}] 冬 'winter', [tu^{31}] 毒 'poison', [t^{h}o^{34}] 拖 'pull', [t^{h}u^{451}] 土 'soil', [t^{h}u^{31}] 图 'picture', [t^{h}ai^{34}] 胎 'tyre', [t^{h}ai^{31}] 台 'platform', [t^{h}i^{34}] 梯 'ladder', [t^{h}i^{324}] 剃 'shave', [t^{h}ɑɯ^{451}] 讨 'mooch', [t^{h}ɑɯ^{31}] 桃 'peach', [t^{h}iɑɯ^{31}] 条 'strip', [t^{h}ɐɯ^{451}] 抖 'shake', [t^{h}ɐɯ^{34}] 偷 'steal', [t^{h}ɐɯ^{31}] 头 'head', [t^{h}æ^{34}] 贪 'corrupt', [t^{h}æ^{31}] 潭 'pond', [t^{h}ɑ^{31}] 踏 'tread', [t^{h}ã^{451}] 毯 'blanket', [t^{h}ɑ^{31}] 塔 'tower', [t^{h}jã^{34}] 添 'add', [t^{h}jã^{31}] 甜 'sweat', [t^{h}je^{31}] 贴 'paste', [t^{h}ã^{324}] 炭 'coal', [t^{h}ã^{31}] 弹 'pop', [t^{h}jã^{34}] 天 'sky', [t^{h}jã^{31}] 田 'field', [t^{h}je^{31}] 铁 'iron', [t^{h}o^{31}] 脱 'take off', [t^{h}ɐn^{34}] 吞 'swallow', [t^{h}ɑŋ^{34}] 汤 'soup', [t^{h}ɑŋ^{31}] 糖 'candy', [t^{h}o^{31}] 托 'lift', [t^{h}ɐn^{31}] 藤 'vine', [t^{h}e^{31}] 特 'very', [t^{h}in ^{34}] 厅 'office', [t^{h}in^{34}] 听 'listen', [t^{h}in^{31}] 停 'stop', [t^{h}in^{451}] 挺 'very', [t^{h}i^{31}] 踢 'kick', [t^{h}oŋ^{34}] 通 'unblock', [t^{h}oŋ^{451}] 桶 'bucket', [t^{h}oŋ^{324}] 痛 'ache', [t^{h}oŋ^{31}] 铜 'copper', [t^{h}oŋ^{451}] 统 'all', [ko^{34}] 歌 'song', [ko^{324}] 个 'piece', [ko^{451}] 果 'fruit', [ko^{324}] 过 'pass', [kwa^{34}] 瓜 'melon', [ku^{451}] 古 'ancient', [kai^{34}] 该 'should', [kai^{451}] 改 'change', [kai^{324}] 盖 'cover', [kai^{34}] 街 'street', [kai^{451}] 解 'work out', [kwai^{324}] 怪 'odd', [kwai^{451}] 拐 'turn', [kwai^{324}] 挂 'hang', [kwei^{324}] 桂 'laurel', [kwei^{34}] 规 'rule', [kwei^{324}] 跪 'kneel', [kwei^{34}] 龟 'tortoise', [kwei^{324}] 柜 'cabinet', [kwei^{451}] 鬼 'ghost', [kwei^{324}] 贵 'expensive', [kɑɯ^{34}] 高 'tall', [kɐɯ^{34}] 钩 'hook', [kɐɯ^{451}] 狗 'dog', [kɐɯ^{324}] 够 'enough', [kã^{451}] 感 'feeling', [ko^{31}] 鸽 'dove', [kæ^{34}] 甘 'sweet', [kã^{451}] 敢 'dare to', [kã^{34}] 肝 'liver', [ko^{31}] 割 'cut', [kwã^{34}] 官 'officer', [kwã^{34}] 关 'close', [kwã^{324}] 惯 'be used to', [kwɑ^{31}] 刮 'scrape', [kɐn^{34}] 根 'root', [kwɐn^{451}] 滚 'roll', [ku^{31}] 骨 'bone', [kɑŋ^{34}] 钢 'steel', [ko^{31}] 各 'each', [kwɑŋ^{34}] 光 'light', [ko^{31}] 郭 'a last name', [ko^{31}] 角 'angle', [kue^{31}] 国 'country', [kɐn^{34}] 更 'even more', [kɐn^{324}] 梗 'stalk', [ke^{31}] 格 'grid', [kɐn^{34}] 耕 'plough', [ke^{31}] 隔 'partition', [koŋ^{34}] 公 'male', [ku^{31}]

谷 ‘grain’, [koŋ^{34}] 宫 ‘palace’, [koŋ^{34}] 恭 ‘respectful’, [koŋ^{324}] 共 ‘together’, [k^{h}o^{451}] 可 ‘can’, [k^{h}o^{324}] 课‘ ‘lesson’, [k^{h}u^{34}] 箍 ‘hoop’, [k^{h}u^{451}] 苦 ‘bitter’, [k^{h}u^{324}] 裤 ‘trousers’, [k^{h}ai^{34}] 开 ‘open’, [k^{h}wai^{451}] 块 ‘piece’, [k^{h}wai^{324}] 快 ‘quick’, [k^{h}wei^{34}] 亏 ‘deficit’, [k^{h}ɑɯ^{324}] 靠 ‘depend on’, [k^{h}ɑɯ^{34}] 敲 ‘knock’, [k^{h}ɐɯ^{451}] 口 ‘mouth’, [k^{h} ã^{324}] 看 ‘look’, [k^{h}o^{31}] 渴 ‘thirsty’, [k^{h}wã^{34}] 宽 ‘width’, [k^{h}we^{31}] 阔 ‘broad’, [k^{h}wɐn^{324}] 困 ‘sleepy’, [k^{h}ɑŋ^{34}] 糠 ‘chaff’, [k^{h}wɑŋ^{34}] 筐 ‘basket’, [k^{h}wɑŋ^{31}] 狂 ‘mad’, [k^{h}o^{31}] 壳 ‘shuck’, [k^{h}ɐn ^{451}] 肯 ‘agree’, [k^{h}e^{31}] 刻 ‘carve’, [k^{h}ɐn^{34}] 坑 ‘pit’, [k^{h}e^{31}] 客 ‘guest’, [k^{h}oŋ^{451}] 孔 ‘hole’, [k^{h}u^{31}] 哭 ‘cry’

Appendix B. List of items that contributed to the plot of monophthong formants in Figure 9

[pa^{31}] 爸 ‘father’, [p^{h}a^{31}] 扒 ‘scrabble’, [ta^{31}] 达 ‘reach’, [t^{h}a^{31}] 塔 ‘tower’, [m^{b}a^{31}] 麻 ‘hemp’, [la^{31}] 拿 ‘take’, [pi^{31}] 笔 ‘pen’, [p^{h}i^{31}] 皮 ‘skin’, [ti^{31}] 敌 ‘enemy’, [t^{h}i^{31}] 题 ‘question’, [m^{b}i^{31}] 迷 ‘secret’, [l^{d}i^{31}] 梨 ‘pear’, [pu^{31}] 不 ‘no’, [p^{h}u^{31}] 仆 ‘servant’, [tu^{31}] 毒 ‘poison’, [t^{h}u^{31}] 涂 ‘paint’, [m^{b}u^{31}] 木 ‘wood’, [lu^{31}] 奴 ‘slave’, [pe^{31}] 白 ‘white’, [p^{h}e^{31}] 拍 ‘pat’, [te^{31}] 得 ‘get’, [t^{h}e^{31}] 特 ‘very’, [m^{b}e^{31}] 麦 ‘grain’, [le^{31}] 勒 ‘rein’, [po^{31}] 钵 ‘bowl’, [p^{h}o^{31}] 婆 ‘old woman’, [to^{31}] 夺 ‘deprive’, [t^{h}o^{31}] 坨 ‘lump’, [m^{b}o^{31}] 莫 ‘no’, [lo^{31}] 罗 ‘a surname’, [pã^{324}] 板 ‘board’, [p^{h}ã^{31}] 盘 ‘dish’, [tã^{34}] 弹 ‘carry’, [t^{h}ã^{31}] 弹 ‘bounce’, [m^{b}ã^{324}] 慢 ‘slow’, [lã^{31}] 蓝 ‘blue’, [ɚ^{31}] 儿 ‘son’, [ɚ^{451}] 耳 ‘ear’, [ɚ^{324}] 二 ‘two’. [ts$\underline{ɻ}^{31}$] 汁 ‘juice’, [ts$^{h}\underline{ɻ}^{31}$] 吃 ‘eat’, [s$\underline{ɻ}^{34}$] 丝 ‘silk’, [z$\underline{ɻ}^{31}$] 日 ‘sun’, [s$\underline{ɻ}^{451}$] 四 ‘four’

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