Segmental-Tonal Alignment Constraints in Southern Min

Yishan Huang
Department of Linguistics
The University of Sydney
Sydney, Australia
yishan.huang@sydney.edu.au

***Abstract*—Zhangzhou Southern Min is theoretically assumed to have 7320 possible syllables but more than 70% of them are not attested in the empirical data, implying substantial constrains governing the segmental sequencing and segmental-suprasegmental alignment. This study investigates phonotactic constraints on tonal behaviors at the syllable level. It examines in what way tonal phonotactics occur and what mechanisms have blocked the co-occurrences between tones and syllable components (onsets and finals). The exploration is built upon an exhaustive survey on all possible combinations of tone, onset, and final to formulate attestable syllables that further perform lexical functions in this Sinitic dialect, which laid out a solid foundation for both diachronic and synchronic explanations. It substantially stretches our knowledge of tonal phonotactics as an important phonological phenomenon in Southern Min, while serving as a model for thorough investigations across Sinitic languages. It also contributes important linguistic data to the typology of phonotactics in world's natural languages, while shedding an important light on using experimental methods to model how human beings constrain speech patterns in their mental grammar and language practices.**

Keywords*— *Phonotactics, tones, syllable components, mechanisms, Zhangzhou

I. Introduction

Sounds do not randomly combine with each other to form a functional syllable and/or a word. Instead, there are constraints, known as phonotactics, posing restrictions on the segmental-segmental sequencing [1-7] and the segmental-suprasegmental alignment [8]. For example, the segmental string *lbick is practically unacceptable, because the liquid sound [l] is phonetically more sonorous than the voiced obstruent [b]; their combination as an onset cluster violates the sonority sequencing principle which prefers a rising sonority from syllable edge to nucleus [9-10]. The phonotactics not only can determine the syllable structure of given languages, but also can categorize the sequences of phonemes into linguistically permissible and impermissible strings. For example, English allows nearly any type of consonants to occur in the syllable-final position, whereas languages like Spanish, Japanese, and Chinese have strict consonants about syllable-final consonants [6]. In Mandarin Chinese, there theoretically should have 1900 possible syllables (without tones), but only about 400 syllables are practically used in conversation, implying a substantial number of constraints that prohibit the occurrence of about 1500 syllables [7]. Similarly, Cantonese has about 1900 distinct syllables (with tones), which only encompasses around 36% of 5130 logically possible syllables [3]. The strong divergency between the theoretical assumption and the practically attested number of syllables has continually motivated linguists to explore and explain why there are so many theoretically possible syllables missing from the real inventory? How the consonantal and vocalic sequences are constrained; and what generalisation can be formulated with respect to the phonological combinations.

Inspired by the intriguing phenomenon of phonotactics, this study is designed to explore how the tonal and segmental alignment is constrained to form empirically attested syllables in Zhangzhou Southern Min, a Sinitic dialect spoken in southern Fujian province of mainland China. This dialect possesses a rich inventory of eight citation tones, 15 syllables onset, and 61 finals that refer to all syllable components excluding onsets [8] and [11]. Theoretically, there should have 7320 possible syllables; yet, based on the tabulating results of Huang [11]'s rhyme tables, only 2105 syllables are practically attested, and 5215 slots show phonological gaps. Each lexical tone is theoretically assumed to generate 915 syllables; however, the attested number is far less than the assumption, with 98 syllables obtained under tone 8 and 392 under tone 1. This reveals that more than 71% of logically possible syllables are missing from the practically permissible syllable inventory and implies that substantial phonological constraints have blocked segmental-segmental sequencings and the segmental-suprasegmental alignments in real-world utterances of this Sinitic dialect. This paper is particularly designed to explore constraints on the segmental-suprasegmental alignments, referred to as tonal phonotactics in this study. It aims to address two important issues that include how tonal phonotactics occur and what mechanisms have induced substantial tonal phonotactics in Zhangzhou.

This study incorporates five main sections: (a) introduction of Zhangzhou speech and segmental system; (b) description of eight citation tones; (c) discussion of the creativity of individual tones in the production of attested syllables; (d) examination of co-occurrence restrictions between tones and syllable onsets and (e) exploration of co-occurrence restrictions between tones and syllable final. Both synchronic and diachronic perspectives will be given to interpret what have triggered tonal phonotactics in this dialect. The discussion fills in the research gap and substantially stretches and advances our knowledge of the tonal phonotactics as an important phonological phenomenon in Zhangzhou Southern Min. The exploration contributes vital linguistics data to the typology of phonotactics in world's natural languages, while enlightening a direction of using

experimental methods to model speakers' mental grammar of phonotactic restrictions.

II. ZHANGZHOU AND SPEECH

A. Zhangzhou

Zhangzhou is a southern Fujian city in mainland China with a registered population of about 5.05 million in 2020 census. The colloquial language spoken by native Zhangzhou people is Southern Min (also known as Hokkien). It is mutually intelligible with Southern Min varieties of Quanzhou, Xiamen and Taiwan, partially intelligible with Teochew and Leizhou Southern Min but is entirely unintelligible with other Chinese dialects (e.g., Mandarin, Hakka, Cantonese, Wu, and Gan).

Certain regional variation can be observed across its eleven administrative areas [12-14], in particular in the tonal system. For example, the pitch of tone 7 (Yangru in terms of middle Chinese tonal category) is documented as a short high contour [4] in Longhai, a mid-level contour [33] in Changtai, a low rising contour [13] in Dongshan and Zhao'an, as well as a convex contour of either [121] or [131] elsewhere. Given the variation, this study restricts the locality to the urban area of Longwen and Xiangcheng districts, which is conventionally considered to be historically-socially-culturally-linguistically-geographically representative of Zhangzhou [15]. The restriction ensures the derived tonal analysis truly representing the central tendency of this Southern Min dialect as an independent variety.

B. Syllables

A C(G)V(X) syllable template can be generalized to characterize the synchronic syllable structure of Zhangzhou within which onset and nucleus are obligatory while glide and coda are optional [8] and [11]. Oral vowels, nasalised vowels and syllabic nasals can function as nuclei, while postvocalic glides, nasal consonants, and obstruent consonants can serve as codas. The whole segmental system incorporates 15 onsets, 2 prevocalic glides, 13 nucleus, and 8 codas, as summarized in Table 1. Four main syllable types that include CV, CGV, CVX and CGVX can be identified, as illustrated in Table 2 in which tones are transcribed using Chao [16]'s notational system with 5 standing for the highest pitch level and 1 the lowest of individual speakers' pitch range.

Table 1: Zhangzhou Phonemic inventory

Component		Phoneme
C	onset	p, pʰ, ɓ, t, tʰ, ɗ, k, kʰ, ɠ, ts, tsʰ, s, z, ɦ, ʔ
G	glide	j, w
V	nucleus	i, e, ɛ, ɐ, ɔ, ɵ, u, ĩ, ɛ̃, ɐ̃, ɔ̃, m, ŋ
X	coda	j, w, m, n, ŋ, p, t, k

Table 2: Examples for Zhangzhou syllable types

Syllable	Examples		
CV	tĩ35 'sweet'	ɓɐ41 'meat'	tɵ35 'knife'
CGV	sjɐ51 'write'	sjɵ35 'warm'	kwɐ35 'song'
CVX	sim35 'heart'	tit41 'gain'	kut41 'bone'
CGVX	tsjɐp41 'juice'	kwɐj41 'odd'	tsʰjɐt41 'chop'

In this inventory, six onsets /ɓ, ɗ, ɠ, z, ɦ, ʔ/ are transcribed differing from previous studies that document them as (/b, l, g, dz, h, ∅/) [17]-[23]. They are posited based on their auditory impression, acoustic manifestation, and consultation with native speakers, aiming to respect and reflect their phonetic reality [8] and [11]. The two glides of both prevocalic and postvocalic are transcribed as /j/ and /w/, rather than using their corresponding homorganic vowels /i/ and /u/ as posited in all prior studies, to reflect their different phonetic properties and phonological status [8] and [11]. As well as this, a glottal stop coda is consistently poised as a phonemic coda in all prior auditorily-based documentations. However, synchronically, the glottal stop cannot be attested at the syllable coda position as it tends to be deleted, which causes related syllable to become open and evokes the emergence of a new tone [8], [11], and [14].

In addition, within the Sinitic convention, each individual syllables are divided into two parts of Initial (shēngmǔ 声母) and Final (yùnmǔ 韵母), the former corresponds to syllable onset while the latter final refers to all syllable components other than onset [5] and [7]. In Zhangzhou Southern Min, 61 Finals can be constructed in the synchronic data [8] and [11], which can be classified into thirteen specific groups, comprising V (e.g., /kɐ41/ 'teach '), Ṽ (e.g., /kɛ̃41/ 'yeast'), N(e.g., /kŋ41/ 'steel'), GV (e.g., /kjɐ41/ 'post'), GṼ(e.g., /kjɛ̃41/ 'mirror'), VG (e.g., /kɐw41/ 'enough'), ṼG (e.g., /ɠɛ̃w33/ 'root of lotus'), VN (e.g., /kɐŋ41/ 'descend'), VP (e.g., /kɐt41/ 'tie; knot'), GVG (e.g., /kjɐw41/ 'hand over'), GṼG (e.g., /ʔwɛ̃j51'wrench'), GVN (e.g., /kjɐm41/ 'sword'), and GVP (e.g., /kjɐp41/ 'take by force'), depending on the nature of segment that occurs in a specific syllable position. This inventory of 61 final types is different from prior documentations, for example, Ma [12] and ZZG [22] both document 85 finals, while Gao [23] documents 88 finals. This reason for the number reeducation is because the glottal-stop coda has undergone deletion so that finals like /iʔ/, /uʔ/, /ɛʔ/, /oʔ/, /eʔ/, /mʔ/, /aʔ/, /ɔʔ/, /ĩʔ/, /ɔ̃ʔ/, /ãʔ/, /ɛ̃ʔ/, /ŋʔ/, /iaʔ/, /iãʔ/, /ioʔ/, /iɔʔ/, /uaʔ/, /uãʔ/, /ueʔ/, /auʔ/, /ãuʔ/, /iauʔ/, /iãuʔ/, and /uãiʔ/ that Ma (1994) posits are not attested in the synchronic Zhangzhou speech. Likewise, finals like /*uẽ/, /*n/, /*om/, and /*uaŋ/ are also not found synchronically [8] and [11].

The segmental and final inventory serves as a foundation to investigate the productivity of individual Zhangzhou tones to formulate attestable syllables, and how the combinations of tones and syllable components can be constrained, and why they are constrained.

C. Material

The material that this study is built upon come from three main sources. (a) One is from the field data that the author collected in the urban districts of Longwen and Xiangcheng in Zhangzhou between 2015 and 2021 to document and describe Zhangzhou speech. (b) The other source is from 61 rhyme tables that Huang [8] constructed to exhaustively tabulate all possible combinations of individual tones across individual syllable onsets and tones. Upon the 61 rhyme tables, the number of attested syllables can be calculated as a function of each tonal and segmental/final combination, whereby exploring how the tonal phonotactics occur and what have induced the tonal phonotactics in this dialect. (c) The preliminary analysis of phonotactics in Zhangzhou [8].

III. ZHANGZHOU CITATION TONES

The monosyllabic citation tones of Zhangzhou speech have received numerous transcriptions [12-15] and [17-23]. However, all the work, before Huang [14]'s initiatives, identified a seven-way tonal contrast with their pitch descriptions not only differing from each other but also largely different from Huang's work which advocates an eight-way tonal contrast and a multidimensional framework of tonal realisation. For example, tone 2, which corresponds to Yangping tone in terms of Middle Chinese (MC) tonal category, has been transcribed in five different ways, including [212], [13], [12], [23], and [22], which cover contour shapes of dipping, rising, and level [14]-[15]. The inconsistency and inaccuracy in the tonal description not only can impede our understanding of nature of tonal property but also can create substantial confusions in terms of theoretical modelling and interpretation.

As an extension to investigate the nature of Zhangzhou tones, this study adopts Huang [8]'s eight-tone system, which is built upon analyzing acoustic data from 21 native speakers across three linguistic contexts in terms of multidimensional tonal realizations (F0, duration, vowel quality, voice quality, syllable coda type). The phonological description of individual tones is given below, each tone is also given its corresponding name in terms of middle Chinese tonal category. More details about the phonetic and phonological property of Zhangzhou tones can be referred to in Huang [8], [11] and [15]'s research.

Tone 1 Yinping /mid rising/: rising pitch from speakers' middle range to high with an extra-long length, rather than a high-level pitch [12-13] and [17-22] or a high rising contour [23]. This tone is labelled as [35] in this study, e.g., /kɔ35/ 'mushroom', /si35/ 'poetry', /tɐŋ35/ 'east', /tsɛ̃35/ 'to contend', /tsʰjɐ35/ 'vehicle', /swɛ̃35/ 'mountain', /tĩ35/ 'sweet', /ɦɐj35/ 'big'.

Tone 2 Yanping /low level/: level in speakers' lower third pitch range with an extra-long duration, rather than a low rising contour [13] or [12] as described before [12-13] and [17-23]. e.g., /kɔ22/ 'paster', /si22/ 'time', /tɐŋ22/ 'copper', /pɛ̃22/ 'flat', /dɐm22/ 'male', /ɠu22/ 'cow', /tʰɐw22/ 'head', /tsʰɐ22/ 'wood'.

Tone 3 Shang /high falling/: medium-long pitch contour falling from high in speakers' range to low, with a short initial level component. This description is similar to the previous descriptions [12-13] and [17-23], but with a lower offset. e.g., /kɔ51/ 'drum', /si51/ 'to die', /tɐŋ51/ 'to wait', /ɓɛ51/ 'horse', /tsjɐw51/ 'bird', /tsʰjɔ̃51/ 'to rob', /ɦɐj51/ 'sea', /tsu51/ 'host'.

Tone 4 Yinqu /mid falling/: medium-long pitch contour falling from the middle third of speakers' pitch range to low, rather than a low falling [21] contour in most previous descriptions [12-13] and [18-23], or a mid-falling [32] contour [17]. e.g., /kɔ41/ 'to look after', /si41/ 'four', /tɐŋ41/ 'frozen', /kʰɵ41/ 'course', /kʰwɛ̃41/ 'to watch', /ɦi41/ 'drama', /kʰɛ41/ 'guest', /ɗu41/ 'scrub', /ʔɐj41/ 'love'

Tone 5 Yangqu /mid-level/: extra long and level contour in the middle third of speakers' pitch range, rather than at a low range [22] in most previous work [12-13] and [17-23]. e.g., /ɦɔ33/ 'rain', /si33/ 'yes', /tɐŋ33/ 'heavy', /tjan33/ 'electricity', /pɛ̃33/ 'illness', /zi33/ 'character'.

Tone 6 Yinru /short stopped mid fall/: mid falling pitch as in tone 4, but with a salient short duration. The transcription [41] is different from previous work of a low-falling [12-13] and [17-23]. Syllables in this tone end in obstruent codas at the underlying level, but the codas tend not to be realised in the utterance-final context but are realised non-utterance finally. High vowels are diphthongised. e.g., /kɔk41/ 'country', /sik41/ 'colour', /kut41/ 'bone', /kip41/ 'urgent', /ɦwɐt41/ 'law', /ʔik41/ 'one', /tsʰit41/ 'seven'.

Tone 7 Yangru /stopped low level with a final fall/: similar pitch to the low-level tone 2, but with a slight final fall due to the depressing effect by creaky phonation, and with a shorter duration. It is labelled as [221] in citation in this study which differs from previous transcriptions of a low convex contour [121] contour [12-13] and [19-23], or a low rising contour of [13] [17] or [12] [18]. Syllables of this tone have underlying obstruent codas that tend not to be realised in citation but are identifiable in the non-utterance-final context. High vowels are diphthongized. e.g., /tɔk221/ 'poison', /sik221/ 'cooked', /dɐk221/ 'six', /tit221/ 'straight', /tsɐp221/ 'ten', /zit221/ 'sun'.

Tone 8 New tone /low level/: extra-long and level contour in speakers' lower third pitch range. This tone is posited as a new tone emerging from the synchronic deletion of glottal stop coda in syllables of tone 7, corresponding to Yangru tone in terms of Middle Chinese tonal category [8], [11], and [14]. This proposal is based on the phonetic fact that the parametrical realizations of this tone 8 are different from those of Yangru tone 7 in both citation and sandhi contexts. Specifically, tone 7 presents a low-level tendency with a final fall [221], extra-long duration, high vowel diphthongization, creakily voiced vowels in citation. On the contrary, tone 8 shows a low-level contour with an extra-long duration [22], breathy high vowel and modally-voiced low vowel. As well as this, this tone appears to have the same pitch contour [22] and extra-long duration as tone 2 in citation; however, they have different realizations in non-right-most contexts: tone 2 is realized as a mid-level [33], while this tone as a mid- falling contour [32]. This tone is thus proposed as a new tone to respect the phonetic reality, it also reflects the diachronic evolvement of sound change and associated phonetic and phonological effect. e.g., /pɛ22/ 'white', /tsi22/ 'tongue', /dɐ22/ 'wax', /dwɐ22/ 'spicy', /tsjɐ22/ 'eat', /tjɵ22/ 'right'.

IV. TONAL PHONOTACTICS

A. Basic phonotactics in Zhangzhou

Zhangzhou presents a substantial number of constraints on the formation of attested syllables. Assuming 15 onsets, 61 finals, and 8 tones, there should theoretically have 7320 (=15*61*8) permissible syllables that would be generated. However, based on the calculation result on Huang's rhyme tables, only 2105 syllables are attested in the synchronic empirical data, implying about 5215 syllables, occupying as many as 71%, are missing from the permissible syllable inventory [8]. Specifically, each onset is logically expected to produce 488 (=61finals * 8 tones) possible syllables; each final is able to generate 120 (=15 finals * 8 tones) possible syllables, and each tone is expected to formulate 915 (=15 onsets * 61 finals) possible syllables; however, the number of syllables that each constituent empirically generates is far less

than the assumption. For example, only 117 syllables practically occur in Tone 7 and 98 in Tone 8, while only 44 syllables are attested under the nasalized vowel /ĩ/, and 14 under the vowel /ɔ̃/. Likewise, 127 syllables are obtained under the unaspirated labial stop /p/, while only 33 syllables under the voiced alveolar fricative /z/, by far fewer than the assumption of 488 syllables for each onset.

This section mainly explores the ways in which tonal phonotactics occur, and what mechanisms have blocked the occurrence of about 5215 logically permissible syllables in Zhangzhou. Three aspects are thus examined from both synchronic and diachronic perspectives, including (a) creativity of individual tones in the formation of attestable syllables; (b) co-occurrence restrictions between tones and syllables onsets; and (c) co-occurrence restrictions between tones and syllables finals.

B. Creativity of tones

Individual tones vary considerably in their creativity of empirically attested syllables in Zhangzhou Southern Min. This can be seen in Table 3 and Figure 1that the number range from 98 under tone 8 to 392 under tone 1, far less than the theoretically assumed number of 915 (=15 onsets * 61 finals) that each tone is logically able to generate. The strong gap suggests that substantial constraints have been governing the alignments between tones and syllable components, which are induced by several diachronic and synchronic factors.

Table 3: The number of attested syllables under tones

Tone	MC	Pitch	Syllable
Tone 1	Yinping	[35]	392
Tone 2	Yangping	[22]	343
Tone 3	Shang	[51]	352
Tone 4	Yinqu	[41]	360
Tone 5	Yangqu	[33]	315
Tone 6	Yinru	[41]	128
Tone 7	Yangru	[221]	117
Tone 8	Yangru (new)	[22]	98

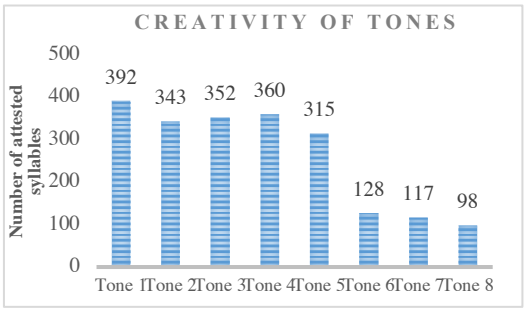

Figure 1: The number of attested syllables across tones.

(1) Tones 6, 7 and 8 have fewer syllables attestable than any other tones. For example, tone 2 can generate 342 syllables, while tone 7 can only generate 117 syllables, about three times less. Similarly, tone 4 can generate 360 syllables, whereas tone 6 that presents a similar mid-high falling F0/pitch contour can only produce 128, also about three time fewer. This gap can be ascribed to the asymmetrical distribution of syllable coda types with respect to tonal categories. Diachronically, those tones that are associated with obstruent-ending syllables are referred to as stopped tones, whereas those tones that are associated with sonorant-ending syllables are referred to unstopped tones [6], [8] and [14]. In Zhangzhou speech, as shown in table 4, tones 6 and 7 can only relate to syllables that end in obstruent codas. Tone 8 is related to those syllables that are historically transcribed with a glottal stop in tone 7 but synchronically lose the glottal stop coda and related syllables have become open. Thus, the strict restrictions on the syllable coda type can substantially impact the productivity of tones to formulate syllables.

Table 4: Asymmetrical distribution of codas and tones

Tone		Pitch	Zero	Sonorant	Obstruent
Un-stopped	1	35	+	+	-
	2	22	+	+	-
	3	51	+	+	-
	4	41	+	+	-
	5	33	+	+	-
	8	22	+	-	-
Stopped	6	41	-	-	+
	7	221	-	-	+

(2) Yin-registered tones have more syllables attested than Yang-registered tones. As shown in table 3, 392 syllables are attested under Yinping while 343 under Yangping. Likewise, 360 syllables are attested with Yinqu tone, while 315 syllables are attested with Yangqu. Similarly, there have 128 in Yinru tone but 117 in Yangru. This divergency between Yin and Yang registered tones can be seen as a consequence resulting from the constraint of syllable onset type. This is because Yin-registered tones are historically associated with voiceless onsets, whereas Yang-registered tones with voiced onsets [8], [11], and [14]. Voiced sounds are universally more marked because of an extra articulatory effort of vocal fold vibration over the arituculation, which can restrict their productivity in the creation of syllables.

(3) Yang-registered tones (2, 5, 7, 8) are dominantly level-pitched in citation, while the Yin-registered tones favor a falling contour (tones 3, 4, and 6). The distribution of pitch contour shapes can be regarded being conditioned by the register type, which is diachronically determined by the voicing status of syllable onsets, as mentioned above. In addition, a rising contour appears to be the least favored in this dialect as it can only occur in one tone. This reflects its most marked status, because it requests more time to complete an articulatory gesture than falling and leveling contours [24-25].

(4) Yang-registered tones locate in the pitch range lower than Yin-registered tones. For example, Yinping is distributed in the mid and above pitch range, while Yangping in the lower range. This is because Yin-registered tones are diachronically associated with voiceless onsets, while Yang-registered tones are related to voiced onsets. The voiced onsets are cross-linguistically acknowledged to have a depressing effect on subsequent F0/pitch contours, which is often reported in Asian tonal languages [26-27].

C. Co-occurrence constraints between tones and onsets

Significant constraints occur on co-occurrence between tones and onsets, as summarized in Table 5, in which I, II, III,

and IV correspond to the Middle Chinese (MC) tones of Ping, Shang, Qu, and Ru, while a and b represent the Yin and Yang registers, respectively. Such tonal phonotactics are triggered by both synchronic and diachronic factors.

Table 5: The number of attested syllables with respect to the onset-tone combination

	T1	T2	T3	T4	T5	T6	T7	T8
	[35]	[22]	[51]	[41]	[33]	[41]	[221]	[22]
	Ia	Ib	II	IIIa	IIIb	IVa	IVb	IVb
p	22	18	22	22	23	7	9	4
pʰ	20	16	14	23	11	7	3	5
b	14	30	25	10	26	3	8	8
t	34	30	25	33	31	10	11	6
tʰ	26	20	17	24	16	9	3	5
d	23	32	35	23	32	6	13	10
k	36	23	31	33	24	13	8	7
kʰ	32	17	22	26	9	11	6	6
g	3	24	12	7	17	1	10	5
ts	36	27	31	34	28	12	11	10
tsʰ	35	15	25	30	14	11	5	7
s	37	24	29	34	22	13	8	7
z	2	9	6	1	6	1	6	2
h	33	28	25	29	28	12	9	8
ʔ	39	30	33	31	28	12	7	8

(1) Onsets occur least often in tones 6, 7 and 8. This reduction is understandable that can be considered resulting from the constraint of syllable coda type on these three tones. As discussed above, tones 6 and 7 can only be aligned with obstruent cods, while tone 8 is related to the glottal stop coda which is synchronically deleted. The special requitement on syllable coda types can substantially affect the alignment of tone and onset to formulate attested syllables.

(2) For those onsets that have a contrast in aspiration, the aspirated onsets (/pʰ, tʰ, kʰ, tsʰ /) mostly have less attested syllables than the unaspirated voiceless onsets (/p, t, k, ts/) across tones. This reflects aspiration as a marked feature that can affect their productivity.

(3) For those onsets that have a phonemic contrast in voicing, the voiced ones (/b, d, g, z/) have fewer syllables attested than their voiceless counterparts of aspirated (/pʰ, tʰ, kʰ/) and/or unaspirated (/p, t, k, s/) in Yin-registered tones but more in Yang-registered tones. This changing manifestation can be seen as a consequence of diachronic constraint. Yin-registered tones are diachronically associated with voiceless onsets, so that syllables of voiced onsets are less likely to occur. On the contrary, Yang-registered tones are historically assumed to contain voiced onsets, so that, more syllables can be attested with voice onsets in the synchronic data.

(4) The voiced alveolar fricative /z/ appears to be the least productivity across most tones. For example, only 1 syllable can be attested with this onset in tones 4 and 6, while in other tonal environments, the number is found not exceeding 10, such as in tone 2, it can generate 9 attested syllables. This reflects its most marked status, such as it cannot occur in any final whose nucleus features a nasality. So that syllables like *zṼ, *zN, *zGṼ, *zṼG, *zGṼG are all prohibited to occur, but this onset is allowed to occur in syllables ending in a nasal coda, such as syllable type zVN (/zim51/ ‘tolerate’), zGVN (/zjɐn51/ ‘infect’) are both attestable.

D. Co-occurrence constraints between tones and finals

Significant constraints also occur on the co-occurrence between tones and finals. As seen in Table 6, the number of attested syllables varies considerably across individual combinations but is far less than the theoretical assumption of 915 under each tone. Several generations can be made to explain what have blocked the occurrence of those theoretically possible syllables.

Table 6: The number of attested syllables with respect to the onset-final combination

	T1	T2	T3	T4	T5	T6	T7	T8
	[35]	[22]	[51]	[41]	[33]	[41]	[221]	[22]
	Ia	Ib	II	IIIa	IIIb	IVa	IVb	IVb
V	76	69	75	74	67	0	0	41
Ṽ	30	22	23	28	24	0	0	7
N	10	6	7	9	5	0	0	5
VN	94	89	83	83	72	0	0	0
GV	50	43	40	64	47	0	0	31
GṼ	39	29	32	29	28	0	0	1
VG	22	18	24	22	19	0	0	4
ṼG	7	3	6	3	7	0	0	3
GVG	14	15	11	11	8	0	0	3
GṼG	3	2	3	1	0	0	0	3
GVN	47	47	48	36	38	0	0	0
VP	0	0	0	0	0	86	76	0
GVP	0	0	0	0	0	42	41	0

(1) Among the finals containing only a monophthong, the syllabic nasal N generates significantly fewer syllables than oral vowel V and nasalised vowel Ṽ across tones. This can be interpreted resulting from (a) nasal consonants have the highest markedness to be a syllable nucleus; (b) only two nasals can behave syllabically, contrasting to several oral vowels and four nasalised vowels, and (c) they suffer from severe constraints in segmental sequences. For example, syllables like *bN, *dN, *gN, and *zN are not allowed to exist in the real-world data.

(2) Final types of VP and GVP can only occur in the stopped tones 6 and 7. No syllables can be attested with them occurring in any other tonal environment. This reflects the historical constraint that requires obstruent coda-ending syllables to occur in stopped tone, also known as Ru tones.

(3) Finals that contain a nasalised vowel (Ṽ, GṼ, ṼG, GṼG) consistently have fewer syllables attested than their oral counterparts (V, GV, VG, GVG) across the tones that they can be assigned to. For example, 76 syllables are attested under the final V in tone 1 while only 30 are found in final Ṽ. This reflects the constraint from the marked feature of nasality on the formation of attested syllables.

(4) Finals containing a post-vocalic glide (VG, ṼG) generate fewer attested syllables than finals containing a pre-vocalic glide (GV, GṼ). For example, GV finals can produce 64 syllables in Tone 4, contrasting to 22 with the VG final. This reflects the post-vocalic glide is more marked than the pre-vocalic one, which constrains their productivity.

(5) Final GṼG appears to be the most marked, because only 12 syllables can be attested under this final across tones. This is understandable from the articulatory perspective, because the complexity of its internal structure that contains both nasality and post-vocalic glide dampens its creativity.

(6) Final VN appears to be the most productive, because it can generate the largest number of attested across unstopped tones. For example, 94 syllables can be attested under the VN type in tone 1, followed by 76 syllables under the V type, and 50 syllables under the GV type. No syllables can be attested with the VN type in tone 8, because this tone historically requests a glottal stop as the coda.

V. Conclusion

As discussed, a substantial number of constraints pose restrictions on the segmental-tonal alignment and segmental-sequencing at the syllable level in Zhangzhou Southern Min, resulting in that more than 71% of theoretically permissible syllables cannot be attested in the synchronic speech. This study is particularly designed to explore how tonal phonotactics occur, how individual tones vary in their productivity in the creation of attested syllables, what mechanisms have constrained the alignment between individual tones and both onsets and finals to form syllables. Diachronically, the historical convention on the selection of certain syllable coda types and onset types in particular tonal environments can substantially affect the tonal alignments with syllable components. Synchronically, the marked features of aspiration, voicing, and nasality, along with the complexity of syllable structures can extensively constrain the ability of segments to combine with tones to formulate syllables that can be attested empirically.

This exploration has broadened and advanced our knowledge of tonal phonotactics as an important language phenomenon in Southern Min, while contributing a model to investigate areal characteristics of tonal constraint within the Sino-Tibetan languages, in particular in those languages of rich and complex tonal contrasts. This study also provides well-attested data to the typology of phonotactics in world's natural languages, extending our understanding beyond the conventional perspective of segmental sequencing constraints. It also sheds an important light on using the experimental methods, such as perceptual test and lexical frequency processing, to model speakers' mental grammar of phonotactic restrictions, whereby improving our cognition of the nature of human languages.

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