Fricative vowels as an intermediate stage of vowel apicalization

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Diphthongization and apicalization are two commonly detected phonetic and/or phonological processes for the development of high vowels, with the process of apicalization being of particular importance to the phonology of Chinese dialects. This paper describes acoustics and articulation of fricative vowels in the Suzhou dialect of Wu Chinese. Acquiring frication initiates the sound change. The production of fricative vowels in Suzhou is characterized by visible turbulent frication from the spectrograms, and a significant lower Harmonics-to-Noise Ratio vis-à-vis the plain counterparts. The acoustic study suggests that spectral characteristics of fricative vowels play a more important role in defining the vowel contrasts. The fricative high front vowels have comparatively greater F1 and smaller F2 and F3 values than their plain counterparts, and in the acoustic F1/F2 plane, the fricative vowels are located in an intermediate position between their plain and apical counterparts. The articulatory study revealed that that not only tongue dorsum but also tongue blade are involved in the production of fricative high front vowels in Suzhou. Phonologically, plain high front vowels, fricative high front vowels, and apical vowels distinguish in active place of articulation, namely being anterodorsal, laminal, and apical respectively; and frication becomes a concomitant and redundant feature in the production of fricative or apical vowels. It is concluded that the fine-grained phonetic details suggest that the fricative high front vowels in Suzhou is at an intermediate stage of vowel apicalization in terms of both acoustics and articulation.

Keywords: fricative vowels, apical vowels, apicalization, Suzhou Wu

1. Introduction

Apical vowels are widely distributed in Chinese dialects (Karlgren 1915–26), whereas fricative vowels or strident vowels are less known in Chinese dialects (Hu 2007; Ling 2011) as well as in other languages (Ladefoged & Maddieson 1990). Apical vowels

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are not classified as a vowel category in the tradition of the International Phonetic Alphabet (IPA) (IPA 1999); rather, they are treated as homorganic syllabic sibilants or approximants, as demonstrated by IPA illustrations in Standard Chinese (Lee & Zee 2003), Shanghai Wu (Chen & Gussenhoven 2015), Hakka (Lee & Zee 2009), etc. There is nevertheless a long tradition in Chinese linguistics for the use of non-IPA symbols [ɿ ʅ ɻ ʮ] for apical vowels since Karlgren (1915–26). Take the most studied Standard Chinese (Beijing Mandarin) for example, the two apical vowels [ɿ ʅ] are homorganic with the preceding sibilants [ts tsʰ s] or [tʂ tʂʰ ʂ ɻ] respectively but are less constricted than their sibilant counterparts (Zhou & Wu 1963; Bao 1984; Ladefoged & Wu 1984; Lee-Kim 2014). That is, [ɿ ʅ] are not voiced sibilants; they are approximants, which is comparable to the high front vowel [i]. Cheng (1973) even used [ɨ] for the transcription of apical vowels.

Apical vowels are of particular interest in Chinese phonetics and phonology, and the process of apicalization played an important role for the formation of phonologies of modern Chinese dialects. Diachronically, apical vowels in Chinese dialects are developed from high front vowels [i]/[y] in Middle Chinese (Karlgren 1915–26). And apicalization is part of historical vowel shift. Vowel shift is a natural phonological process widely detected in the world's languages (Labov 1994). For instance, lower vowels became higher during the Great Vowel Shift in the historical development of English (Stockwell 2002). And the high vowels [i u] in Middle English became diphthongized [aɪ aʊ] respectively in Modern English. Similarly, diphthongization is a common phonetic and/or phonological process for the development of high vowels in Chinese dialects (Zhu 2004; Hu 2013). But the historical phonology of Chinese dialects differs from English in that in addition to diphthongization, apicalization is the other common choice for the development of high vowels in Chinese dialects (Zhu 2004; Zhao 2007; Hu 2007). In fact, apicalization is a shared innovation for nearly all the major Chinese dialect families except Cantonese.

Fricative vowels were sporadically reported in Chinese dialects such as Wu (Chao 1928), Jianghuai Mandarin (Wu 1995), and other dialect families. Shi (1998) gave a detailed review of these dialects including Wu, Hui, Jin, Jianhuai Mandarin, Northwestern Mandarin, and other Mandarin dialect subfamilies, and concluded that fricative high vowels would finally develop into apical vowels. Zhao (2007) explained the phonological process of apicalization ([i] > [ɿ]) especially in the Jixi Hui dialect. Zhu (2004) gave a more general picture for the development of high vowels in Chinese dialects. However, previous studies are all comparative dialectological works and gave no phonetic details to explain why fricative high vowels would develop into apical vowels. This paper does not intend to have a thorough investigation of apicalization in Chinese dialects. Instead, it examines fricative vowels in a particular dialect, the Suzhou dialect of Wu Chinese; and it

aims to explain why fricative vowels are at an intermediate stage of the apicalization for the high front vowels.

Suzhou is a representative dialect for fricative vowels in that in addition to fricative vowels, Suzhou has contrastive plain high front vowels as well as apical vowels. Suzhou has 12 monophthongal vowels that are usually transcribed as [ɿ ʮ i y u ɪ ʏ ɛ ø o æ ɑ] in the literature, and the high vowels [i y u] are characterized by high frication (Chao 1928; Yuan 1960; Wang 1987). The fricative [u] is phonetically realized as [ʊ] or [v], and is not concerned with the main issue of this paper. This paper focuses on fricative high front vowels [i y] and their contrastive counterparts: plain high front vowels [ɪ ʏ], and apical vowels [ɿ ʮ]. [i y] in Suzhou has been described as having high frication for a long period, as it was observed in phonetic transcriptions around a hundred years ago (Ting 2003). They were sometimes transcribed with a superscript fricative [iᶻ yᶻ] in the literature since there is no diacritic for frication in the transcription of vowels in IPA; by using IPA, they could be transcribed with diacritics of *raised*, for instance [i̝], in narrow transcription.

The plain high front vowels in Suzhou are transcribed as [ɪ ʏ]. [ɪ ʏ] have different historical origins and are not paired: [ɪ] is historically from the Xian-shan rhyme groups (咸山攝), which are originally syllables with a nasal coda *[ɪn]; [ʏ] is historically from the Liu rhyme group (流攝). The phonetic transcription for [ɪ] varied in the literature. In Lu's transcription that referred to the Suzhou phonology in the late 19th century, [ɪ] was a diphthong [ie] (Ting 2003: 124); it was a diphthong [iɪ] in Chao (1928: 49); in Yuan (1960: 59–60), it was transcribed as a diphthong [iɪ] after [tɕ tɕʰ ɕ dʑ ɳ] and zero initial (i.e. in onset-less syllables) and as a monophthong [ɪ] elsewhere; it was transcribed as [ɪ] in Wang (1987). It is difficult to comment whether this kind of difference in transcription reflects sound change or could simply be attributed to idiosyncratic, or impressionistic differences among scholars. In our investigation, [ɪ] is always realized as a monophthong.

As in other Chinese dialects such as Mandarin, the apical vowels [ɿ ʮ] only occur after alveolar fricative or affricates [ts tsʰ s z(dz)] in Suzhou. Consequently [ɿ ʮ] and [i y] have a complementary distribution, respectively. But apical vowels are generally treated as phonemes, rather than allophones of high front vowels in Chinese dialects. There are several reasons. First, apical vowels have different phonetic qualities from high front vowels, and they avoided the historical process of palatalization of preceding coronal consonants. Second, as was documented in an earlier variety of Suzhou (Yuan 1960), high front vowels [i y] did occur after alveolar fricatives or affricates. In Yuan (1960: 60), /ts tsʰ s z(dz)/ occurred before [i y] and contrasted with /tɕ tɕʰ ɕ dʑ/ respectively; meanwhile, Yuan mentioned that palatalization had occurred among young speakers. That is, around 1960, one process of palatalization [ts tsʰ s z(dz)] > [tɕ tɕʰ ɕ dʑ]/[i y]) was on-going in Suzhou, when the other process [k kʰ h g] > [tɕ tɕʰ ɕ dʑ]/[i y] had already been completed.

Third, the phonemic treatment of vowels would be at the cost of consonants, and vice versa. On the one hand, if [ɿ ʯ] were treated as allophones of /i y/, it would trigger the process of palatalization [ts tsʰ s z(dz)] > [tɕ tɕʰ ɕ dʑ]/[i y]). On the other hand, [tɕ tɕʰ ɕ dʑ] could alternatively be treated as allophones of /ts tsʰ s z(dz)/ respectively; and in that case, [i y] contrast with [ɿ ʯ] respectively, since they both occur after /ts tsʰ s z(dz)/. Chao (1934) had a detailed analysis of these kinds of phonetic and/or phonological concerns and concluded as the "non uniqueness of phonemic solutions of phonetic systems".

This paper does not attempt to provide a thorough analysis of vowel apicalization in Suzhou; rather, it focuses on the phonetics and phonology of the fricative high front vowels and their corresponding plain high front vowels and apical vowels. Based on the acoustic and articulatory data, it is argued that fricative vowels are an intermediate stage of vowel apicalization, and acquiring frication initiates the sound change, which leads to a subsequent change in (active) place of articulation.

2. Methodology

An acoustic study and two articulatory studies were conducted. The acoustic study was based on 10 male speakers; 1 of them participated in the palatographic and linguagraphic study; 3 of them participated in the electromagnetic articulographic study (EMA, the Carstens AG500 system). All speakers were born and raised in Suzhou and had no long experience staying in other cities. All speakers have no reported speech or hearing disability. Approximate age of the informants was 60 at time of recording.

As shown in Figure 1, during EMA recordings, receiver coils were attached on the upper lip (UL), the lower lip (LL), the gum ridge at the lower teeth (Jaw), and the three points of the tongue, namely the tongue tip (TT), tongue mid (TM), and tongue dorsum (TD) along the midline of the speaker's mid-sagittal plane. In addition, three receiver coils were attached to the bridge of the nose and the bones right behind the ears respectively, serving as reference points for the correction of head movement.

Meaningful monosyllabic words containing all Suzhou vowels, diphthongs, and other rimes were used as test words. All test words are onset-less syllables with a high level tone except the apical vowels that co-occur with a homorganic sibilant. The test word was placed in a carrier sentence [ŋəu231 səʔ5__ pəʔ5 nɛ231 tʰiŋ44] 'I read __ for you (to) listen'. Test words were randomized and three repetitions were recorded for each speaker. Audio data were recorded in a quiet room using a Shure SM-58 microphone and an HHB MDP500 Portable MD Recorder. Audio recordings and the palatographic and linguagraphic study were performed during the

second author's fieldtrips. EMA recordings were carried out in the phonetics lab at the Institute of Linguistics, Chinese Academy of Social Sciences. This paper focuses on the target fricative high front vowels and their plain and apical counterparts.

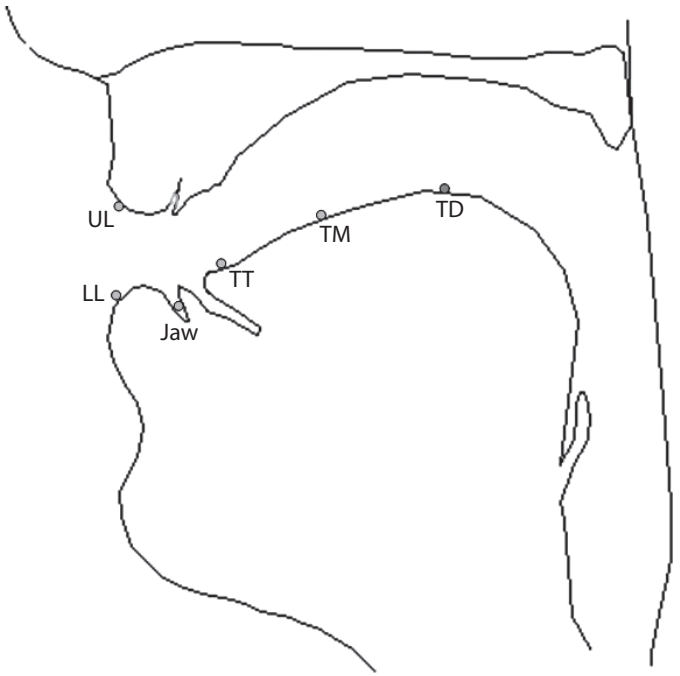

Figure 1. Sensor attachments for EMA recordings

Acoustic analysis was carried out in Praat (Boersma 2001). The frequencies of the first three formants (F1 F2 F3) were measured at the temporal midpoint of the target vowel using LPC method. Praat uses a Gaussian-like window and computes the LPC coefficients with the algorithm given by Childers (1978) and Press et al. (1992). Wide-band spectrograms were made for reference. The Harmonics-to-Noise Ratio (HNR) was also measured. HNR assumes that speech signal consists of two components: a harmonic component and an additive noise component (Yumoto et al. 1984; Hillenbrand & Houde 1996; Wayland & Jongman 2003). Therefore it can be used to quantify the frication degree of vowels.

3. Results

As mentioned earlier, diachronically, apical vowels [ɿ ʯ] resulted from an early development of plain high front vowels in Middle Chinese (Karlgren 1915–26). The Suzhou dialect is of particular interest in the understanding of vowel apicalization, as there is a recent phonological development of the fricative [i y] from plain high front vowels, and at the same time, there is a recent development of nasal coda deletion after the plain high front vowels [ɪ ʏ], i.e. [ɪ ʏ] < *[in yn]. Historically, it is a chain shift, namely the plain high front vowels become fricated to avoid phonological merges with the original rhymes with nasal coda *[in yn]. This paper does not intend to give a historical phonological analysis of apicalization. Instead, this paper gives acoustic and articulatory analyses on fricative vowels and related vowel articulations in Suzhou and it explores how fine-grained phonetic details shed light on the explanation of phonological sound change.

The production of fricative high front vowels [i y] in Suzhou is characterized by an audible fricative noise and a visible turbulent frication from the spectrogram. The degree of frication was quantified by the Harmonics-to-Noise Ratio (HNR). As shown in Table 1, the production of the fricative high front vowels [i y] is characterized by a significantly lower HNR vis-à-vis their plain counterparts [ɪ ʏ]. The presence or absence of frication was considered as the major noticeable difference between [i y] and [ɪ ʏ] in previous studies (Chao 1928; Wang 1987; Qian 1992). The phonetic details in this study show that acquiring frication has acoustic as well as articulatory consequences. First, the acoustic data ascertained that acquiring frication results in a spectral difference; second, the articulatory data revealed that there is a difference in lingual articulation for the production of the fricative high front vowels [i y] versus their plain counterparts [ɪ ʏ].

Table 1. Mean HNR in dB of fricative vs. plain [i] in Suzhou

	Mean HNR	**sd**	**F-value**	**P-value**
i	16.1	4.6	24.041	$P < 0.0001$
ɪ	20.9	3.9		
y	19.6	4.3	13.222	$P = 0.001$
ʏ	22.8	3.2		

Figure 2 plotted the 12 monophthongal vowels [ɿ ʯ i y u ɪ ʏ ɛ ø o æ ɑ] of Suzhou in the acoustic vowel plane by using the first formant (F1) as ordinate and second formant (F2) as abscissa with the origin of the axes to the top right. The axes are Bark-scaled (Smith & Abel 1999), while the values along the coordinates are still labeled in Hertz. Vowel ellipses were drawn with radii of two standard deviations

along axes oriented along the principal components of each vowel cluster (Disner 1983). Each vowel ellipse indicates the dispersion of 30 data points of a vowel (3 repetitions × 10 speakers).

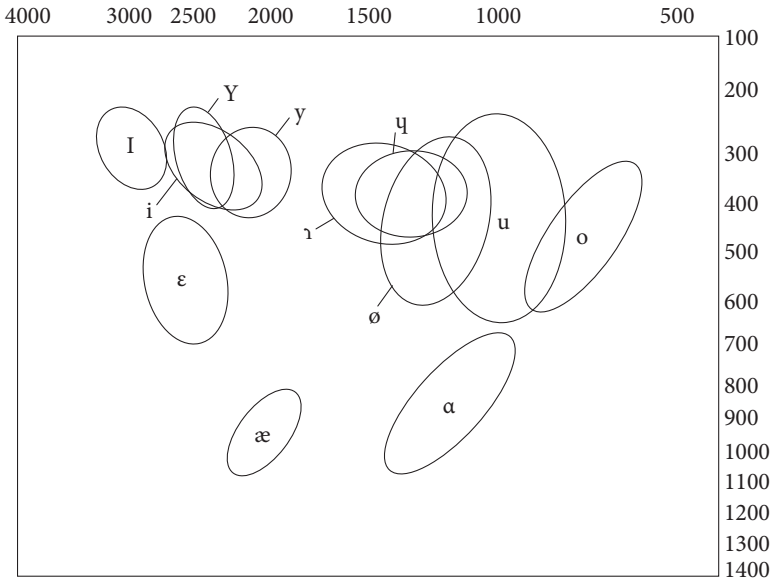

Figure 2. Suzhou vowels

Suzhou vowels exhibit a quadrilateral distribution in the acoustic F1/F2 vowel plane: the low vowels [æ ɑ] contrast in backness; the mid vowels [ɛ ø o] contrast in backness and lip rounding; [ɿ ʮ i y u ɪ ʏ] are all located in the region of high vowels. The ellipse of [u] is the most dispersed among all vowels, and overlaps with [ø] and [o]. As mentioned earlier, this paper focuses on the fricative as well as plain high front vowels and apical vowels [ɿ ʮ i y ɪ ʏ]. The fricative high front vowels [i y] are located to the right of their plain counterparts [ɪ ʏ] respectively in the acoustic vowel plane; the apical vowels [ɿ ʮ] are located in a central high position. It can be seen from the figure that the ellipses for [i y] extensively overlap with each other, and so do the ellipses for [ɿ ʮ], suggesting that [i y] and [ɿ ʮ] cannot be distinguished by the first two formants, respectively. This is probably due to the effect of frication by fricative and apical vowels. Nevertheless, they differ in F3. The means and standard deviations in Herz for the first three formants of [ɿ ʮ i y ɪ ʏ] were summarized in Table 2. It can be seen from the table that the unrounded [i ɪ ɿ] and their rounded counterparts [y ʏ ʮ] differ in F3, respectively, as lip rounding lowers all formant values but has more apparent effect on higher (F3) than lower (F1 and F2) formants.

It can also be seen from Figure 2 that ellipses for the fricative and plain front vowels, especially the rounded pair [y ʏ], overlap with each other to some extent. As shown in Table 3, one-way ANOVAs yielded significant difference in F2 and F3 for the unrounded pair [i ɪ], and significant difference in F2 for the rounded pair [y ʏ]. The fact that the rounded pair [y ʏ] is spectrally less differentiated than the unrounded pair [i ɪ] implies potential sound change. It was reported in the literature that the merge of [y ʏ] occurred in certain regional varieties and some accent of young speakers of the Suzhou dialect (Li 1988).

Table 2. Means and standard deviations in Herz for the first three formants (F_1 F_2 F_3) of the vowels [ɿ ʮ i y ɪ ʏ] in Suzhou

	F_1		F_2		F_3	
	Mean	**s.d.**	**Mean**	**s.d.**	**Mean**	**s.d.**
ɿ	344	60	1179	89	2741	294
ʮ	337	55	1141	122	2623	226
i	274	38	2022	112	3012	199
y	283	45	1902	84	2395	170
ɪ	269	38	2353	205	3421	296
ʏ	297	17	2073	150	2389	190

Table 3. One-way ANOVAs of the first three formants for [i ɪ] and [y ʏ]

	F1	**F-value**	**P-value**	**F2**	**F-value**	**P-value**	**F3**	**F-value**	**P-value**
i	274	0.186	0.668	2022	58.102	<0.0001	3012	38.753	<0.0001
ɪ	269			2353			3421		
y	283	1.090	0.303	1902	22.153	<0.0001	2395	0.010	0.921
ʏ	297			2073			2389		

The formant data have shown so far that the fricative high front vowels [i y] are located in an intermediate position between their plain counterparts [ɪ ʏ] and apical counterparts [ɿ ʮ] in the acoustic vowel plane. The fact that the fricative vowels [i y] have formant patterns different to their plain counterparts [ɪ ʏ] suggests that vowel quality has shifted after acquiring frication. The question is what happened when plain high front vowels acquired frication? The linguagraphic data revealed that more laminal part of the tongue is involved in the production of the fricative [i y], as compared to the plain [ɪ ʏ], which is basically anterodorsal. As shown in Figure 3, more anterior part of the tongue is involved in the production of the fricative [i y] vis-à-vis their plain counterparts [ɪ ʏ]; and accordingly, not only the hard palate but also post-alveolar region are involved in the production of the fricative [i y].

Figure 3. Palatograms (upper) and linguagrams (lower) of [i ɪ y ʏ] (from left to right) in Suzhou

And the EMA study confirms a comparatively advanced lingual configuration in the production of the fricative vowels vis-à-vis their plain counterparts. The mean tongue positions were plotted in Figure 4, with the contour of the speaker's hard palate superimposed for reference. The three sampled tongue points were connected by lines, and speakers were facing right. High front vowels are palatal in terms of constriction location, and are produced with an approximation of the mid tongue point (TM) towards the hard palate. In all the three speakers, TM is less approximated towards the hard palate for the fricative [i y] than for the plain high front vowel [ɪ]. And at the same time, the sampled tongue tip point TT is more constricted for the fricative [i y] than for the plain high front vowel [ɪ] in general. Figure 5 plots mean lingual configurations for the plain and fricative high front vowels [ɪ i] with their apical counterpart [ɿ]. The sampled three tongue points form a lingual configuration for [ɿ] generally different to [ɪ i]. Apical vowels are double articulated in the sense that in addition to tongue dorsum, the tongue tip is also involved in the production (Bao 1984; Hu 2003). Taken the linguographic and palatographic data into account together, it suffices to summarize that in addition to tongue dorsum, the anterior part of the tongue, i.e. tongue blade, is also involved in the production of fricative high front vowels in Suzhou. The fricative high front vowels [i y] in Suzhou can thus be defined as laminal vowels from an articulatory point of view. And it can be seen from Figure 5 that, in terms of the three sampled tongue points, the fricative [i] shares a generally similar lingual configuration with the palin [ɪ] in Speaker 1 and 3, but with the apical [ɿ] in Speaker 2. In summary, the

production of the fricative high front vowels in Suzhou is characterized by an intermediate articulatory configuration between their plain and apical counterparts.

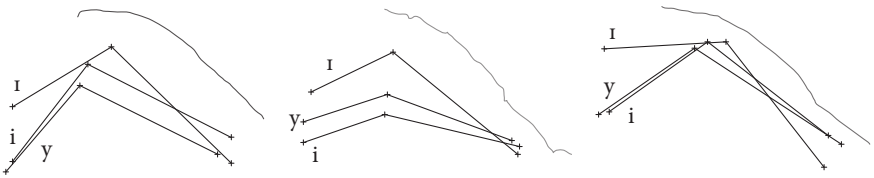

Figure 4. Lingual configurations for the fricative high front vowels [i y] and the plain [ɪ] from three male speakers of Suzhou (speakers face right)

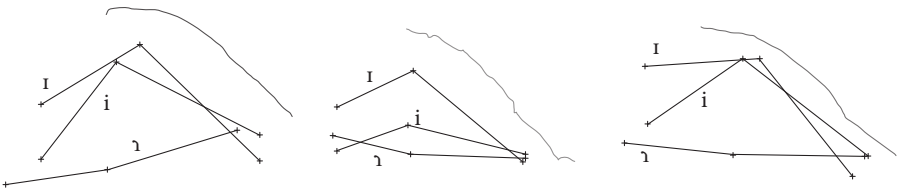

Figure 5. Lingual configurations for the plain and fricative high front vowels and apical vowel [ɪ i ɿ] from three male speakers of Suzhou (Speakers face right)

4. Discussion and conclusion

Diphthongization and apicalization are two commonly detected phonetic and/or phonological processes for the development of high vowels (Hu 2007; 2013), with the process of apicalization being of particular importance to the phonology of Chinese dialects. Acquiring frication initiates the sound change (Chao 1928; Shi 1998). This paper examined fricative high front vowels and their plain and apical counterparts in Suzhou Wu Chinese. The acoustic data suggest that in addition to audible frication, spectral characteristics play a more important role in defining the fricative vowels and vowel contrasts distinguishing plain, fricative, and apical vowels. The formant data show that the fricative high front vowels [i y] have comparatively greater F1 and smaller F2 and F3 values than their plain counterparts [ɪ ʏ] respectively and the difference is significant in F2 and F3 for the unrounded pair [i ɪ] and in F2 for the rounded pair [y ʏ]. And the fricative high front vowels [i y] are located between their plain high front counterparts [ɪ ʏ] and apical counterparts [ɿ ʮ] in the acoustic F1/F2 vowel plane. The articulatory data revealed that not only tongue dorsum but also tongue blade are involved in the production of fricative high front vowels in Suzhou. And the fricative high front vowels in Suzhou could

thus be defined as laminal vowels. Phonologically, plain high front vowels, fricative high front vowels, and apical vowels distinguish in active place of articulation, namely being anterodorsal, laminal, and apical respectively; and frication becomes a concomitant and redundant feature in the production of fricative or apical vowels.

Diachronically, fricative vowels are at an intermediate stage of vowel apicalization. Apicalization is part of natural phonological process of vowel shift, and played a unique role for the historical phonological development from Middle Chinese to Modern Chinese dialects (Karlgren 1915–26). Apical vowels are treated as syllabic voiced sibilants or approximants in the tradition of IPA. Ladefoged & Maddieson (1996: 314) viewed fricative vowels as a more general term referring to not only apical vowels but also other related vowel articulations. In Chinese dialects, acquiring frication and further becoming apicalized are both detected in recent developments for high vowels (Shi 1998; Zhu 2004; Zhao 2007). As for the Suzhou case concerned here, fricative vowels [i y] are from a recent development while apical vowels [ɿ ʯ] are from an early development. Acoustic and articulatory data show how acquiring frication changes lingual configuration in the production of high front vowels in Suzhou. Plain and fricative high front vowels, and apical vowels are in fact in a continuum in terms of the involvement of the front part of the tongue, i.e. tongue tip and blade: no apical gesture for plain high front vowels, an additional laminal gesture to anterodorsal articulation for the fricative high front vowels, and an additional apical gesture to dorsal constriction for apical vowels. However, it should be admitted that modeling study of articulatory tubes is required to further explore the details of articulatory-to-acoustic relations concerning the palatal-to-apical continuum of vowel production.

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Abbreviations

EMA	electromagnetic articulographic study	LL	lower lip
F1	first formant	TT	tongue tip
F2	second formant	TM	tongue mid
F3	third formant	TD	tongue dorsum
HNR	Harmonics-to-Noise Ratio	UL	upper lip
IPA	International Phonetic Alphabet		

References

Bao, Huai-qiao. 1984. Putonghua danyuanyin de shengli jieshi [Physiological explanations for the monophthongs in Putonghua]. *Zhongguo Yuwen* [Studies of the Chinese Language] 2. 117–127.

Boersma, Paul. 2001. Praat, a system for doing phonetics by computer. *Glot International* 5(9–10). 341–345.

Chao, Yuen Ren. 1928. *Studies in the modern Wu dialects*. Beijing: Tsinghua University.

Chao, Yuen Ren. 1934. The non-uniqueness of phonemic solutions of phonetic systems. *Bulletin of the Institute of History and Philology Academia Sinica* 4(4). 363–398.

Chen, Yiya & Gussenhoven, Carlos. 2015. Shanghai Chinese. *Journal of the International Phonetic Association* 45. 321–337. https://doi.org/10.1017/S0025100315000043

Cheng, Chin-Chuan. 1973. *A synchronic phonology of Mandarin Chinese*. The Hague: Mouton. https://doi.org/10.1515/9783110866407

Childers, Donald G. 1978. *Modern spectrum analysis*. New York: IEEE Press.

Disner, Sandra Ferrari. 1983. *Working Papers in Phonetics 58: Vowel quality: the relation between universal and language-specific factors*. Los Angeles: UCLA.

Hillenbrand, James & Houde, Robert A. 1996. Acoustic correlates of breathy vocal quality: Dysphonic voices and continuous speech. *Journal of Speech and Hearing Research* 39. 311–321. https://doi.org/10.1044/jshr.3902.311

Hu, Fang. 2003. An acoustic and articulatory analysis of vowels in Ningbo Chinese. In Solé, Maria-Josep & Recasens, Daniel & Romero, Joaquín (eds.), *Proceedings of the 15th International Congress of Phonetic Sciences*, 3017–3020. Barcelona: Universitat Autónoma de Barcelona.

Hu, Fang. 2007. Lun Ningbo fangyan he Suzhou fangyan qiangao yuanyin de qubie tezheng – jian tan gaoyuanyin jixu gaohua xianxiang [On the distinctive features for the high front vowels in Ningbo and Suzhou Wu Chinese – with reference to the sound change of high vowels]. *Zhongguo Yuwen* [Studies of the Chinese Language] 5. 455–465.

Hu, Fang. 2013. Falling diphthongs have a dynamic target while rising diphthongs have two targets. *Journal of the Acoustical Society of America* 134(5). 4199. (Full paper in Chinese in *Yuyan Yanjiu Jikan* [Collected Papers on Language Studies] 10. 12–37.) https://doi.org/10.1121/1.4831405

International Phonetic Association. 1999. *Handbook of the International Phonetic Association: A guide to the use of the International Phonetic Alphabet*. Cambridge: Cambridge University Press.

Karlgren, Bernhard. 1915–26. *Études sur la phonologie chinoise* (Archives d' Études Orientales 15). Uppsala: K. W. Appelberg.

Labov, William. 1994. *Principles of linguistic change*. Cambridge: Blackwell.

Ladefoged, Peter & Maddieson, Ian. 1990. Vowels of the world's languages. *Journal of Phonetics* 18. 93–122.

Ladefoged, Peter & Maddieson, Ian. 1996. *The sounds of the world's languages*. Oxford: Blackwell.

Ladefoged, Peter & Wu, Zhongji. 1984. Places of articulation: An investigation of Pekingese fricatives and affricates. *Journal of Phonetics* 12. 267–278.

Lee, Wai-Sum & Zee, Eric. 2003. Standard Chinese (Beijing). *Journal of the International Phonetic Association* 33. 109–112. https://doi.org/10.1017/S0025100303001208

Lee, Wai-Sum & Zee, Eric. 2009. Hakka Chinese. *Journal of the International Phonetic Association* 39. 107–111. https://doi.org/10.1017/S0025100308003599

Lee-Kim, Sang-Im. 2014. Revisiting Mandarin 'apical vowels': An articulatory and acoustic study. *Journal of the International Phonetic Association* 44. 261–282. https://doi.org/10.1017/S0025100314000267

Li, Xiao-Fan. 1988. *Cong Suzhou qingnianren yuyin kan Suzhou yinxi liushinian lai de yanbian* [The phonological development of Suzhou Wu in 60 years as manifested in young speakers' speech]. Beijing: Peking University. (Master's thesis.)

Ling, Feng. 2011. Suzhouhua [i] yuanyin de yuyinxue fenxi [A phonetic study of vowel [i] in Suzhou Chinese]. In *Yuyanxue luncong* [Studies in Linguistics] 43. 177–193.

Press, William H. & Teukolsky, Saul A. & Vetterling, William T. & Flannery, Brian P. 1992. *Numerical recipes in C: The art of scientific computing*. 2nd edn. Cambridge: Cambridge University Press.

Qian, Nairong. 1992. *Dangdai Wuyu yanjiu* [Studies in contemporary Wu dialects]. Shanghai: Shanghai Educational Publishing House.

Shi, Rujie. 1998. Hanyu fangyan zhong gaoyuanyin de qiangmoca qingxiang [On the high frication in high vowels in Chinese dialects]. *Yuyan Yanjiu* [Studies in Language and Linguistics] 1998(1). 100–109.

Smith, Julius O. & Abel, Jonathan S. 1999. Bark and ERB bilinear transforms. *IEEE Transactions on Speech and Audio Processing* 7(6). 697–708. https://doi.org/10.1109/89.799695

Stockwell, Robert. 2002. How much shifting actually occurred in the historical English vowel shift? In Minkova, Donka & Stockwell, Robert (eds.), *Studies in the history of the English language: A millennial perspective*. New York: Mouton de Gruyter. https://doi.org/10.1515/9783110197143

Ting, Pang-hsin. 2003. *Yibai nian qian de Suzhouhua* [The Suzhou dialect 100 years ago]. Shanghai: Shanghai Educational Publishing House.

Wang, Ping. 1987. Suzhou yinxi zai fenxi [Revisiting Suzhou phonology]. *Yuyan Yanjiu* [Studies in Language and Linguistics] 1987(1). 41–48.

Wayland, Ratree & Jongman, Allard. 2003. Acoustic correlates of breathy and clear vowels: The case of Khmer. *Journal of Phonetics* 31. 181–201. https://doi.org/10.1016/S0095-4470(02)00086-4

Wu, Wei. 1995. Heifeihua "-i" "-y" yinjie shengyunmu qianhua tantao [On the development of -i and -y syllables in Heifei Mandarin]. *Yuwen Yanjiu* [Linguistic Research] 1995(3). 58–60.

Yuan, Jiahua (ed.). 1960. *Hanyu fangyan gaiyao* [Outline of Chinese dialects]. Beijing: Wenzi Gaige Chubanshe.

Yumoto, Eiji & Sasaki, Yumi & Okamura, Hiroshi. 1984. Harmonics-to-Noise Ratio and psychophysical measurement of the degree of hoarseness. *Journal of Speech, Language, and Hearing Research* 27. 2–6. https://doi.org/10.1044/jshr.2701.02

Zhao, Rixin. 2007. Hanyu fangyan zhong de [i] > [ɿ] [[i] > [ɿ] in Chinese dialects]. *Zhongguo Yuwen* [Studies of the Chinese Language] 2007(1). 46–54.

Zhou, Dianfu & Wu, Zongji. 1963. *Putonghua fayin tupu* [Articulatory diagrams of Standard Chinese]. Beijing: The Commercial Press.

Zhu, Xiaonong. 2004. Hanyu yuanyin de goading chuwei [Sound changes of high vowels in Chinese dialects]. *Zhongguo Yuwen* [Studies of the Chinese Language] 2004(5). 440–451.

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