ARTICULATORY VARIABILITY AND FRICATIVE NOISE IN APICAL VOWELS

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ABSTRACT

Standard Mandarin (SM) *apical vowels* have tongue postures similar to the fricative consonants that obligatorily precede them, but are thought to lack the consonants' fricative noise. Lee-Kim [10] argues that in SM apical vowels, a slight reduction of constriction at the tongue blade or tip reduces fricative noise, essentially resulting in syllabic approximants. Using lingual ultrasound to examine articulation of apical vowels in SM, we argue that other articulatory adjustments may also limit frication in apical vowels, but that these strategies are implemented variably such that some speakers occasionally exhibit frication. This articulatory variety mostly maps to frictionless or approximant-like apical vowels in SM, but we find no reason to rule out fricativized apical vowels as possible phonetic segments in SM or other languages.

Keywords: Apical vowels, frication, ultrasound, Mandarin Chinese

1. INTRODUCTION

Apical vowels, common in the Chinese languages, are produced with coronal constrictions [15, 10] homorganic with preceding fricative or affricate consonants. They are similar to Swedish *Viby-i* [2] and are likely similar to *fricative vowels*, found at least in Wu Chinese [12] and several languages of West Africa [4], although the latter are phonemically contrastive with high front vowels in most cases and do not impose similar restrictions on initial consonants. Their phonetic realization and phonological representation of apical vowels have been subject to debate, having been described as vowels [8, 7], syllabic fricatives [1, 6], and syllabic approximants [10].

Standard Mandarin (SM) has two apical vowels, alveolar [ɿ] and flat postalveolar [ʅ];[1] the latter is often imprecisely referred to as "retroflex" [9]. Both are thought to be allophones of /i/ following (post)alveolar fricatives or affricates. In spite of their fricative-like tongue posture, they are typically either weakly fricated or free of frication [10], suggesting small adjustments to suppress frication that would otherwise be produced. Lee-Kim [10] shows such an adjustment in an ultrasound study of one SM speaker: a slight lowering of the tongue blade during apical vowels. We sought to reproduce this result with more speakers, as apical vowels are rarely studied with direct articulatory imaging, and interspeaker articulatory and acoustic variability is likely.

2. METHODS

Our study sought to replicate earlier findings [10] that tongue postures for the SM apical vowels, unlike other SM vowels, do not substantially differ from co-occurring fricative onset consonants, and that a release of the fricative constriction at the tongue tip or blade occurs during apical vowels, resulting in the absence of frication.

2.1. Data acquisition

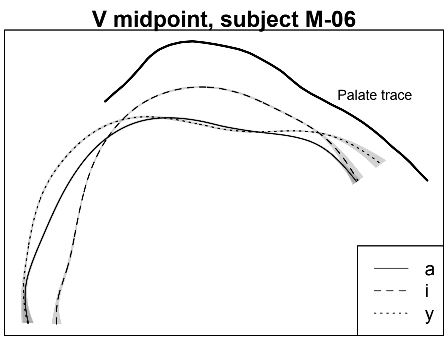
Stimuli consisted of the eight disyllabic items used in Lee-Kim [10]; each item's first CV syllable contains the segments of interest (Table 1). Target CV syllables have a high level tone and are followed by a velar fricative /x/ in the onset of the second syllable. Eight filler words were also included. Eight native speakers of SM who reported no speech or hearing difficulties took part in the study. Data collected from three subjects (S2, S5, S7) were excluded due to technical problems. The five remaining subjects (4 F, 1 M, mean age = 20.8y) are from cities in northern China (two subjects from Shenyang; one each from Beijing, Dalian, and Baoji, Shaanxi province).

Subjects were recorded in a sound-attenuated booth. Stimuli were presented in six blocks of sixteen items in random order. Stimuli were displayed as simplified Chinese characters on a teleprompter one meter in front of the subject at eye level. Subjects read presented stimuli in the frame sentence used in Lee-Kim [10]: 我说___ 这个词 [wə^{21} ʃwə^{55} ___ tʂə^{51}kə ts^{h}ɿ^{213}] "I say ___, this word." The first block was used for familiarization; no data was recorded. Ultrasound video and audio were recorded for 40 tokens per subject (five tokens each of eight

Table 1: Experimental stimuli for midsagittal sections (all) and coronal sections (shaded only).

	/i/	/a/	/u/
/s/	sɿ^{55} xaw^{214} 撕好 tear well	sa^{55} xwaŋ^{214} 撒谎 tell a lie	su^{55} xaŋ^{35} 苏杭 Su-Hang cities
/ʂ/	ʂʅ^{55} xan^{35} 湿寒 cold and wet	ʂa^{55} xaj^{53} 杀害 murder	ʂu^{55} xan^{53} 书函 letters
/ɕ/	ɕi^{55} xan^{53} 西汉 Western Han	ɕa^{55} xan^{214} 瞎喊 shout foolishly	—

Figure 1: SSANOVA splines for vowel midpoints, midsagittal section, S6. Spline 'y' is [ɿ].



target stimuli).

Ultrasound video in midsagittal section was recorded at 107 fps on an Ultrasonix SonixTablet using a C9-5/10 microconvex transducer held in place by an Articulate Instruments Ltd. stabilization headset. The ultrasound unit remained outside the booth, with the transducer entering through a hole in the booth wall sealed with foam. Synchronized audio (48 kHz sampled, mono) was recorded using an AKG 535 EB microphone and digitized with a Steinberg UR22 USB audio interface.

2.2. Ultrasound analysis

Using Praat TextGrids [3], the CV syllables containing fricatives and (apical) vowels in each target item were segmented by hand. Ultrasound frames corresponding to production of the target CV were processed using Edge Trak to detect tongue surface contours [11]. The frames nearest the midpoints of target C and V tokens were then analyzed using smoothing-spline analysis of variance (SSANOVA) [5]. Palate traces for each subject were generated by averaging the palate contours extracted from five adjacent frames of a recorded swallow task.

3. RESULTS

3.1. Midsagittal ultrasound

The overall location of tongue postures in the oral cavity for the vowels [a], [i], [ɿ] is provided in Figure 1 for S6. Tongue dorsum position is generally lower for [ɿ] (and [ʅ], not shown) than for the high vowels [i] and [u]. During production of [ɿ] and [ʅ] the tongue dorsum is as low and retracted as [a], with the tongue posture differing mainly in the extension and raising of the tongue blade and tip.

Tongue displacement between consonant and vowel midpoints is illustrated in Figure 2. The low tongue dorsum and raised tongue blade and tip in the tongue configuration for [ɿ] and [ʅ] are seen to more closely resemble their onset fricatives [s] and [ʂ] (respectively) than other SM vowels. As such, relatively little tongue displacement occurs when speakers produce a fricative onset consonant and an apical vowel in sequence; in most cases only slight transpositions of the fricative tongue posture occur. In contrast, S1's [ɕi] and other CV sequences elicited all show a greater degree of displacement and change in contour shape. Sequences ([sa], [ʂa], [ɕa], [su], [ʂu]) are not displayed due to space limitations, but unsurprisingly show a much greater degree of within-CV tongue displacement than the stimuli presented here.

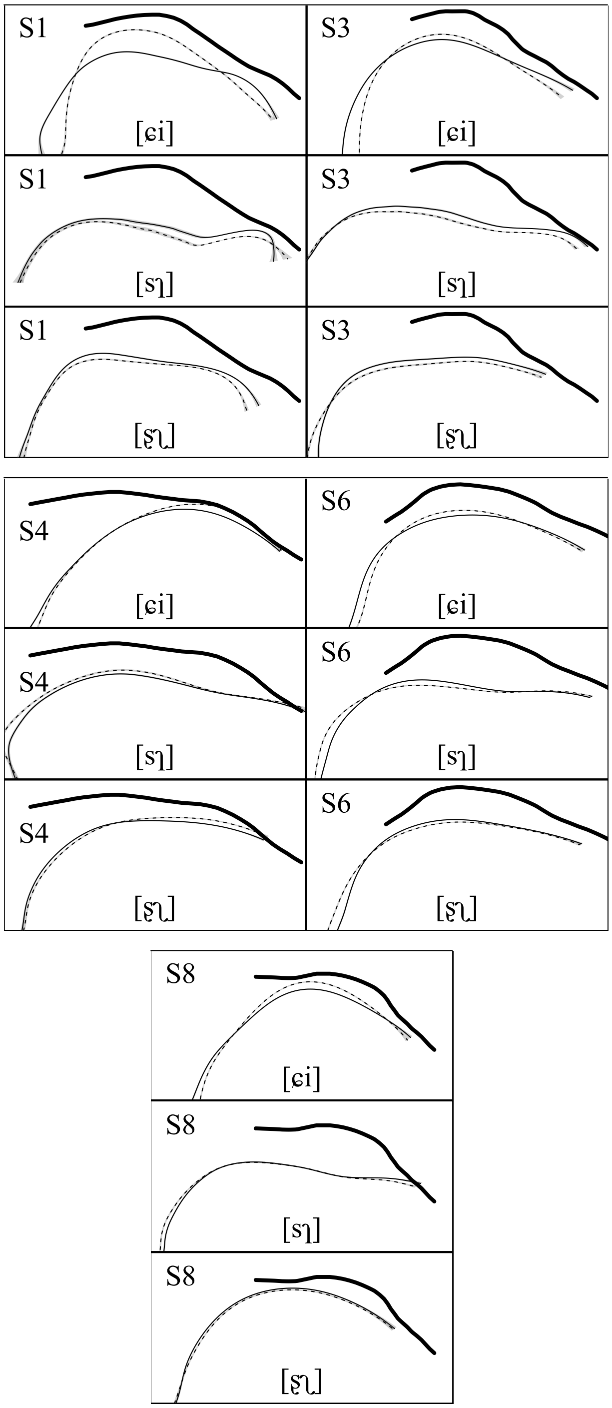
The [i] in the sequence [ɕi] also exhibits substantial similarity with preceding [ɕ] for some speakers (S4, S6, S8), in contrast to other speakers (S1, S3, and the subject in Lee-Kim [10]). Since production of [i] typically involves no raising of the tongue tip or blade [13], this suggests that some speakers maintain the raised-blade posture of the fricative. Neither [i] nor the apical vowels were observed to have substantial frication, however (although see Section 3.2).

Finally, apical vowel production appears to include lingual adjustments not observed in Lee-Kim [10]. A reduced degree of (post)alveolar fricative constriction is indeed observed in S8's [sɿ]. However, concomitant tongue dorsum lowering is observed for subjects' [sɿ] and [ʂʅ] (S1, S3), and tongue dorsum lowering without blade lowering is observed for one subject (S6). S4 *raises* the tongue dorsum during [sɿ] and both the dorsum and blade during [ʂʅ]. The tongue blade appears to be stationary in S4's [sɿ], similar to S6's productions in general. S6's and S8's [ʂʅ] show little to no change in posture.

3.2. Frication check

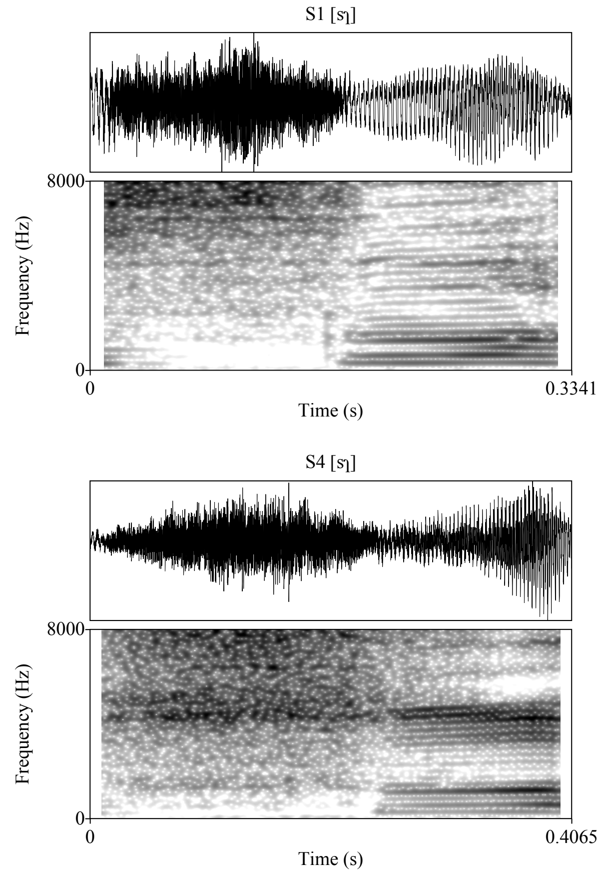
In the absence of a well-accepted means of measuring the presence or absence of an aperiodic noise component of a periodic sound, we offer an impres-

Figure 2: SSANOVA splines for midsagittal contours. C midpoints are solid lines; V midpoints are dotted lines; palate traces are thick solid lines.



sionistic evaluation of the phonetic quality of the recorded apical vowels. The apical vowels in our data exhibit essentially no fricative noise, with a few exceptions confined to one speaker. A typical production of [sɿ] for S1 is shown in Figure 3: a strong periodic signal and clear formant structure are apparent upon inspection of the waveform and spectro-

Figure 3: Productions of [sɿ] for S1 and S4.



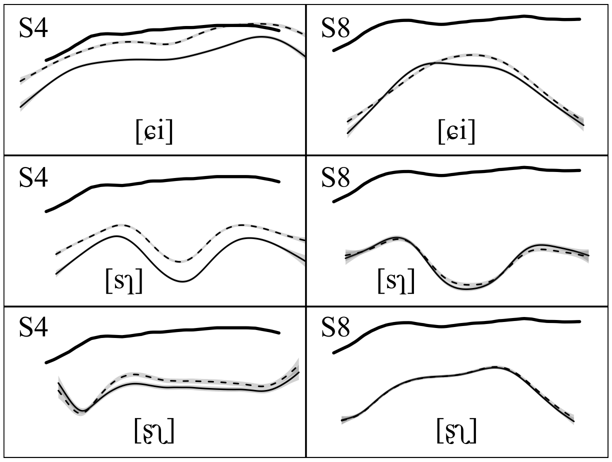
gram. Also notable is the clear and immediate transition between the onset [s] and the apical vowel [ɿ].

What variation does occur in our data suggests that speakers do occasionally produce more noticeable frication during apical vowels: a typical production of [sɿ] for S4, also included in Figure 3, shows some aperiodic noise during the first half of the vowel. The light frication visible in S4's spectrogram falls short of the intensity typical of an onset fricative, but is similar to the light frication observed in fricative vowels in other languages [4]; it may be a consequence of S4's tongue-raising strategy in producing apical vowels. This interspeaker variation remains to be explored more thoroughly, possibly with an acoustic metric that is sensitive to changes in aperiodic spectral components, rather than general spectral profile.

3.3. Follow-up: coronal ultrasound

We carried out a follow-up examination of two unusual apical vowel production strategies. Subjects S4 and S8 did not increase the cross-sectional area of their vocal tracts during production as viewed in

Figure 4: SSANOVA splines for coronal contours. Line types as in Figure 2.



midsagittal section; all else being equal, this should increase the likelihood of frication in apical vowels, but expected frication is only occasionally observed for S4, and not at all for S8. We collected additional ultrasound imaging in a coronal plane at the postalveolar region for these two subjects; it was expected that one or both may exhibit a lingual adjustment not recordable midsagittally, such as cavity expansion by lateral tongue body lowering or increased medial groove width. Data acquisition procedure and analysis was the same as described in Sections 2.1 and 2.2 except that a subset of the stimuli were used (see Table 1) and no filler words included. The obtained images are shown in Figure 4 for [ɕi], [sɿ], and [ʂʅ]. Neither speaker was found to make the expected adjustments: S4 raises the entire coronal section of the tongue blade. Save a change from slightly grooved to domed in [ɕi], S8 does not raise or lower the tongue blade.

4. DISCUSSION

We find a wider variety of lingual adjustments in use during apical vowel production than Lee-Kim [10], including tongue dorsum lowering without blade lowering. Given that corresponding acoustic data tend to lack frication, it appears that the lingual adjustments at issue typically prevent the carryover of frication from the onset fricative into the apical vowel. Lowering the tongue blade, as observed for S1 and S3, may reduce degree of constriction at the critical location where the turbulent jet required for a strident fricative's noise source would be produced. Some subjects (S1, S3, S6 to an extent) also exhibit cavity expansion posterior to this constriction by way of tongue dorsum lowering, which may make turbulence more difficult to maintain due to a decrease in intraoral pressure.

Other strategies are less expected: little to no adjustment (S8, S6) and tongue raising (S4). These do not increase the vocal tract's cross-sectional area and do not provide any obvious source for loss of frication; in fact, S4's raising may correspond with occasional stronger frication. The likely absence of other lingual adjustments visible in coronal section suggests that the crucial frication-preventing factor could be non-lingual for some speakers. The most direct and easily testible possibility is a reduction in airflow. Velic leakage could also lower intraoral air pressure; this adjustment crucially might not produce a large acoustic change in the apical vowels at issue. Likewise, pharyngeal expansion could increase the cross-sectional area of the vocal tract and, all else held equal, decrease intraoral pressure.

While we find that the tongue posture of apical vowels is broadly similar to the posture of their co-occurring onset fricatives, we also observe that this pattern is not restricted to apical vowels: [i] may also exhibit a raised tongue blade through its duration when following the alveolopalatal fricative [ɕ]. The SM variation in [i] may correspond to a first stage in progressively greater coarticulation between the two segments, to the point where the entire syllable is realized with some fricative noise, as reported in some other Chinese dialects as a sort of alveolopalatal apical vowel [14, 12]. These dialects may articulate /i/ similarly to SM, but with more fricative noise than is typically observed in SM.

On the whole, there is a substantial amount of articulatory variation that does not result in correspondingly substantial acoustic variation in SM apical and high vowels, and most speakers exhibit the approximant-like vowel reported by Lee-Kim [10]. More detailed acoustical study of more varieties of apical vowel is needed, however, particularly with a metric that is more sensitive to potential aperiodic components of the vowel signal. The category of apical vowels is likely to encompass more than just solely approximant or solely fricative realizations, especially if one looks beyond SM to other languages, where phonetic implementation is likely to differ.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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[1] To transcribe the SM apical vowels, we make use of traditional [ɿ] and [ʅ], rather than assigning the apical vowels to a second class of segments defined in the IPA (e.g. [ɿ] as the voiced fricative [z̩] or approximant [ɹ̩]). This choice allows us to remain agnostic as to the acoustic realization of the segments.