Tonal register as a motivation for change: a case of High Vowel Fricativization in Changzhou Chinese

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Abstract

This study focuses on the interaction of tonal register and the fricativization of vowels. High Vowel Fricativization (HVF) [1] is a model for the emergence of fricative vowels, which requires vowels to have consistent turbulence to generate a *wall noise source* as the driving force. However, the empirical foundation of the model remains unclear. To investigate this, 40 native speakers of Changzhou Chinese produced a series of CV monosyllabic words with alveolar fricative vowel /z̩/ and its plain counterpart, the high front vowel /i/, as the nucleus across tones. We measured the spectrograms, Zero-crossing Rate (ZCR), Harmonics-to-Noise Ratio (HNR) and several phonation measurements for each token. Results indicate that the high vowel in the lower register exhibits breathy phonation and its HNR/ZCR values are similar to fricative vowels. This suggests that lower register /i/ is produced with audible turbulence, acting as one of the prerequisites for fricativization. Listeners may misperceive the vowel as a new sound category primarily cued by frication noise, eventually spreading the sound to other tonal categories and giving rise to a fricative vowel /z̩/. Overall, this study provides the phonetic foundation for the emergence of frication noise in fricative vowels, arguing that register can be a motivation for change in the fricativization of high vowels.

Index Terms: fricative vowel; fricativization; sound change; breathy phonation; tone; register

1. Introduction

1.1. Fricative vowels

Fricative vowels, an unusual segment type cross-linguistically, exhibit articulatory and acoustic features from both voiced fricatives and high vowels. Phonetically, they exhibit clear formant structures but are accompanied by fricative-like strident aperiodic noise [2]. The phonological status of fricative vowels has been a subject of debate, with analyses suggesting their classification as syllabic fricatives [3] or approximants [4]. Nevertheless, these segments are generally acknowledged as syllabic nuclei in contrast to other non-obstruent segments. Fricative vowels are scarce in languages worldwide but have been identified in a variety of Chinese languages (e.g. Suzhou Chinese [5], [6], [7], [8]; Nuosu Yi [9], [10]; Ersu [11]) and other languages including Grassfield Bantu [2] and a Swedish dialect [12].

The diachronic development of fricative vowels is believed to originate from high vowels [13], [1] which become apical vowels [8]. The emergence of fricative vowels has been associated with the narrowing of vocal tract constriction [13] and an inherent source of turbulence within the vowels themselves [14]. A comprehensive framework which summarizes and explains the sound change from high vowels to such voiced segments with strident frication is High Vowel Fricativization (HVF) [1]. The phonological shift involves high front vowels developing into alveolar fricative vowels (e.g. [i y] – [z̩ y͡z̩]) as well as high back vowels becoming labial fricative vowels (e.g. [u] – [u͡v u͡β]). There are two prerequisites for HVF. One is that the vowel undergoing the change must create a narrow aperture, facilitating turbulent airflow. Two ultrasound studies on Suzhou Chinese (a variety of Wu Chinese) validate this condition by showing that the alveolar fricative vowels have a tongue dorsum position that is higher than [7] or close to [8] its plain counterpart (i.e. high front vowels). Another prerequisite is the presence of a detectable amount of turbulence in the vocal tract, referred to as a *wall noise source*, acting as the aerodynamic driving force for the emergence of the strident noise in fricative vowels. This precondition is also supported by a fricative-vowel coarticulation study in Huangyan Taizhou Wu Chinese [14]. It was found that in this language, fricative vowels only occur in the lower tonal register. This is because the lower register provides breathy voice quality that functions as the source. However, it is only inferred that increasing airflow caused by slack vocal folds in lower registers is the explanation. The current research seeks to provide experimental evidence and a more conclusive explanation for this.

1.2. Changzhou Chinese

The study focuses on Changzhou Chinese, a variety of Wu Chinese spoken in Changzhou City, to argue that tone (or register) can induce a *wall noise source* by resulting in breathy phonation. High vowels in Changzhou Chinese are distributed in a relatively crowded space (Figure 1). There are three sets of high front vowels, each set has an unrounded and rounded counterpart: high front vowels /i y/, alveolar fricative vowels /z̩ y͡z̩/ and apical vowels /ɿ ʮ/. There are also two sets of high back vowels: high back /u/ and bilabial fricative vowels /u͡v u͡β/.

Changzhou Chinese lexical tones are categorized into upper and lower registers, each characterized by four types of tonal contours: even, rising, going, and entering. However, the lower rising tone (T4) does not occur in modern Changzhou Chinese, because it has fully merged with lower going tone (T6) [14]. Since fricative vowels do not co-occur with checked tones, two checked tones are excluded from this study. Consequently, only 5 lexical tones are applied in the study (see Table 1). T2 and T6, characterised by lower pitch values, are categorized into the lower register, and T1, T3 and T5 with higher pitch values are in the upper register. Apart from pitch, the lower register is reported to be correlated with slack vocal folds [15], [16].

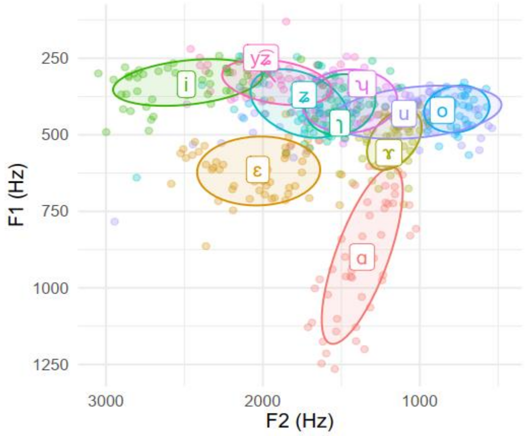

Figure 1: *Monophthongs in open syllables.*

Table 1: *Lexical tones (checked tones are excluded in this study).*

Register	Tone	Pitch
Upper	T1 Upper Even	55
	T3 Upper Rising	35
	T5 Upper Going	52
	~~T7 Upper Entering~~	-
Lower	T2 Upper Even	213
	~~T4 Upper Rising (merged)~~*	-
	T6 Upper Going	232
	~~T8 Upper Entering~~	-

1.3. Research questions

In this study, we aim to answer three research questions: 1) What's the difference between fricative vowel /z̩/ and its plain counterpart /i/? 2) How do tones or tonal registers influence the degree of turbulent noise in /z̩/ and /i/? 3) How does the frication noise in the fricative vowel /z̩/ emerge?

Section 2 outlines the methods for the experiment. Section 3.1 compares frication noise of the fricative vowel and high vowel. Section 3.2 measures the breathiness of lower register high vowels and explains how breathy phonation becomes a *wall noise source*. Sections 4 and 5 revisit the fricativization process and offer conclusions.

2. Methods

2.1. Data collection

The recordings of 40 Changzhou Chinese-Mandarin Chinese bilingual speakers were collected (26F, 14M, aged between 20-65). All speakers were long-term residents from the city centre, speaking the same dialect variety. Thirty-eight speakers were recorded in December 2022, using a Zoom H1N portable condenser microphone; two speakers were recorded in April 2024, using Marantz 660PMD recorder with a Shure 33-984E cardioid dynamic microphone. All speakers were recorded in a quiet room. All were recorded at a sampling rate of 44.1 kHz and saved as .WAV files.

The wordlist contains ten CV-structured monosyllabic words in Changzhou Chinese, with /z̩ i/ as the nucleus across tones (T1, T2, T3, T5, T6). Changzhou Chinese has no standard written form. Therefore, the stimuli words and the sentences were presented with simplified Mandarin Chinese characters on a screen, and the speakers were instructed to read out in Changzhou Chinese. During the recording, each stimulus and frame sentence was repeated three times, generating a total of 3*10*40 = 1200 productions.

2.2. Data processing and analysis

Acoustic data processing was done by Praat [17] and VoiceSauce [18]. To measure the frication noise, we inspected the spectrogram via Praat, and extracted dynamic Zero-crossing Rate (ZCR) and Harmonics-to-Noise Ratio (HNR) as acoustic measurements. ZCR measures the number of times the sound wave crosses the x-axis within a period of time. In this study, it is derived from the zero-crossings per second divided by a window length of 5ms. Higher ZCR values indicate greater frication noise. HNR measures the ratio of periodic to aperiodic signal in the sound. Lower HNR values suggest higher level of noise. Smoothing Spline Analysis of Variance (SSANOVA) models were selected to visualize and compare the ZCR/HNR contour which changed over time.

To outline the breathiness of lower register, we extracted spectral slices from Praat and exported dynamic phonation parameters (CPP, H1*-H2*, H2*-H4*, H1*-An*) using VoiceSauce. SSANOVA models were fit for the phonation parameters.

3. Results

3.1. From high vowel to fricative vowel

3.1.1. Spectrograms

Figure 2 shows spectrograms of an onsetless fricative vowel /z̩^{55}/ (衣, clothes) and an onsetless high vowel /i^{55}/ (烟, smoke). The comparison between them indicates that the fricative vowel exhibits a clear aperiodic energy distribution in the waveform. The frication occurs free of consonantal context. In other words, the fricativization of high vowels is caused by intrinsic characteristics of the vowel itself, rather than coarticulation from proceding obstruents.

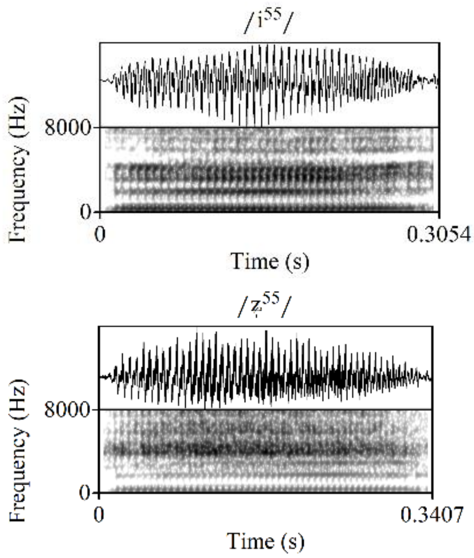

Figure 2: *Spectrograms for fricative vowel /z̩^{55}/* (衣, clothes) *and its counterpart high vowel /i^{55}/* (烟, smoke).

3.1.2. ZCR and HNR across tones: focusing on lower register high vowel

SSANOVA models were fitted to the time-varying HNR/ZCR data of /ʐ̩/ and /i/ across tones (Figure 3, 4). Overall, it suggests that in general, fricative vowels exhibit stronger frication noise than high vowels, which is consistent with the observation in section 3.1.1.

For upper register tones (T1, T3, T5), the difference between the curves of the two vowel types is more prominent, whereas for the lower register tones (T2, T6) the difference appears relatively small. To be specific, compared with the upper register, both HNR and ZCR of lower register high vowel /i/ are lower and are closer to that of the fricative vowel /ʐ̩/. One explanation for this is that lower register vowels incorporate breathiness in phonation, inducing such turbulent noise [19]. An exploration of the breathiness is detailed in section 3.2.

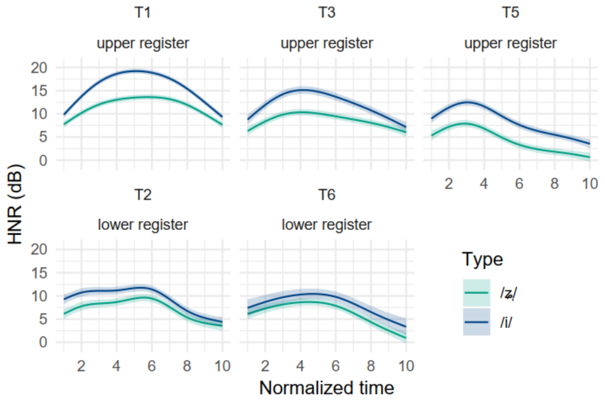

Figure 3: *SSANOVA model fits for time-varying HNR values /ʐ̩/ and /i/ across tone categories. 95% Bayesian confidence intervals presented.*

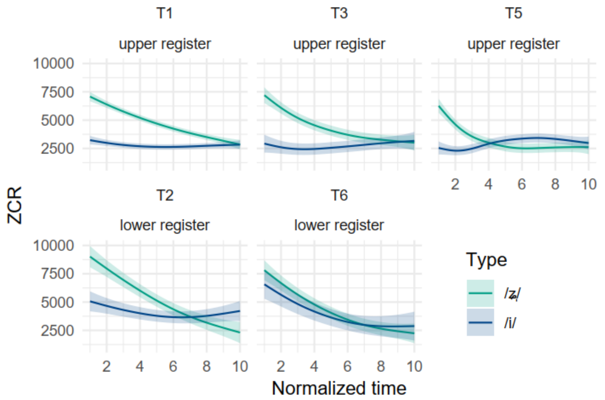

Figure 4: *SSANOVA model fits for time-varying ZCR values /ʐ̩/ and /i/ across tone categories. 95% Bayesian confidence intervals presented.*

3.2. Breathiness as a *wall noise source*

3.2.1. Spectra

Figure 5 shows spectral slices extracted from the middle of upper and lower register /i/ productions from one speaker. The relative amplitude of the first two harmonics (H1, H2) can be seen from the figure. It is assumed that H1 – H2 reflects the Open Quotient (OQ) of the vocal folds, reflecting the degree of glottal tension. A higher H1 – H2 value indicates a breathier voice, and a lower value signifies a modal voice [20], [21], [22]. In this case, /i/ productions from both registers (/i^{55}/ and /i^{213}/) have a strong H1 and a soft H2, which may not display distinctive differences.

However, further examination reveals evidence to support the point that the lower register has a breathy phonation. In comparison to the upper register /i^{55}/, the lower register /i^{213}/ has 1) a more aperiodic spectrum, 2) a reduction in overall amplitude, 3) and a steep tilt in the lower frequencies in the spectrum. According to [23] [24], these are characteristic features of breathy phonation, attributed to the leakage of airflow through the glottis.

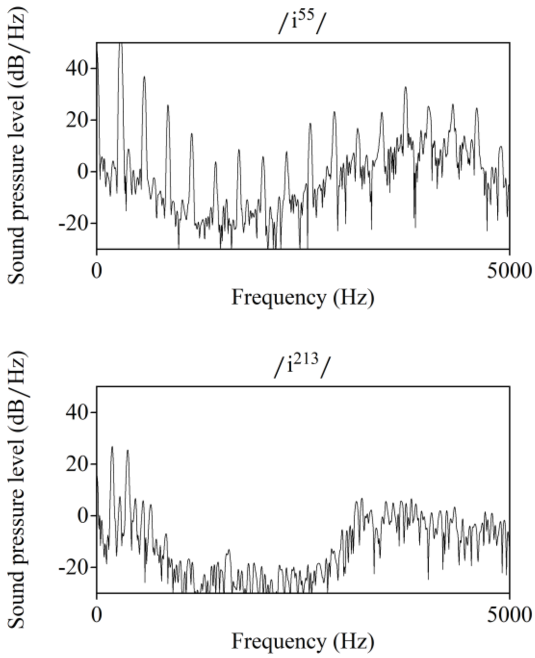

Figure 5: *Example spectral slice for /i^{55}/ (T1) in the upper register and /i^{213}/ (T2) in the lower register.*

3.2.2. Acoustic parameters

In order to further investigate the phonation status of the upper and lower registers, several acoustic parameters related to phonation were measured: spectral tilt H1* - H2* (with formant corrections by [25]), Cepstral peak prominence (CPP), and other phonation-related parameters (H1* - A1*, H1* - A2*, H1* - A3*, H2* - H4*). Significant SSANOVA results were found in the majority of the acoustic parameters (Figure 5). Breathy voice in the lower register is signalled by a larger H1* - H2* in the first half of the vowel, larger values of H1* - An* [26], [27], [28], higher H2* - H4* [24], [29], and a lower cepstral peak [27].

The aerodynamics of breathy phonation is well described [30], [31] such that breathiness is produced with a relatively open glottis with the anterior part of the vocal folds vibrating while also letting air escaping through the posterior part of the vocal folds. The audible turbulence is then generated from the direct airflow through the half-opened glottis. The constricted epilarynx may also take part in the process, but requires further acoustic investigation. The turbulence becomes the airflow that strikes the wall of the vocal tract from a sloping angle, generating a *wall noise source* [32].

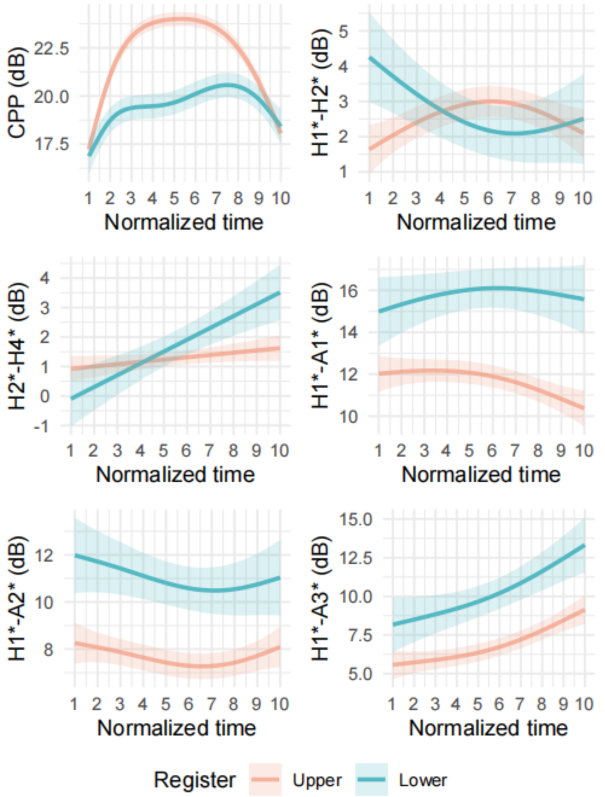

Figure 6: *SSANOVA model fits for phonation measurements of /i/ in upper and lower registers.*

4. Discussion

With acoustic data from Changzhou Chinese, we aim to revisit the fricativization process of HVF in this section. The process involves two preconditions and a process of misperception by listeners.

First, high vowels become hightened while being compressed by the encroachmment of lower vowel categories, a phenomenon well-documented by [13] [33] that /i/ in Wu Chinese is described to be increasingly peripheral. The heightened tension is further evidenced by the crowded vowel space in Changzhou Chinese, as discussed in Section 1.

Meanwhile, there must be a presence of a *wall noise source*. Previous studies have not provided direct observations regarding where *wall noise source* could have originated. In this paper, we present a case that the source originates from the lower register. Lower register high vowels exhibit breathy phonation, where audible turbulence passes through the partially opened vocal folds, generating airflow that strikes the vocal tract wall at a wide angle. This precondition has also been confirmed by [34]. The study highlights that fricative vowels in Huangyan Taizhou Wu Chinese only occur in lower register vowels. So, apart from the constriction between tongue and palate, they conclude that breathy phonation of a lower register is also a crucial element.

The *wall noise source* enhances the air pressure at the constriction between tongue and palate, generating a jet of air striking the upper teeth, which is strident frication noise characteristic of fricative vowels. This frication noise becomes a more informative cue to the new sound category by misperception [34]. Speakers use frication noise as the major cue, displacing formant values as the usual cue. During production, they maintain the frication noise, and extend the feature to other tones, consequently giving rise to fricative vowels.

5. Conclusions

This study explores the emergence of frication noise in fricative vowels, with a specified focus on tones and tonal registers. We explored and used examples from Changzhou Chinese, an under-investigated language variety of Wu Chinese. We found acoustic evidence for the empirical basis of the prerequisite for fricativization. Specifically, we found that breathy phonation from a lower register tone can be a driving force for the transformation from high vowel to fricative vowel. The breathiness plays the role of initial noise, produces more turbulence in the vocal tract and forms fricativization with the narrow constriction of the high vowel /i/. Listeners who perceive this are likely to create a new category in their sound inventory, resembling the fricative /z/. The process of misperception by listeners aligns with the hypo-correction concept by [35]. Subsequently, listeners use frication noise as a highly informative cue and spread this feature to other tones. To maintain this frication as a cue, intentional production of strident frication which directs the airflow to the alveolar ridge gives rise to the fricative vowel /z̩/.

The current paper specifically focuses on the unrounded high front vowel and its counterpart alveolar fricative vowel. Further research should include the rounded high front vowels, high back vowels and cases in which the constriction is at the teeth and lips. In addition, cross-linguistic study in other languages with fricative vowels is also worth investigating, including languages that are tonal in a broad sense (Ryukuan languages [36], Bora [37], Grassfield Bantu [38]) and languages with register systems (e.g. Suzhou Chinese [7], Jixi-Hui Chinese [39]) to explore whether tones or tonal registers are also a crucial factor in vowel fricativization for other languages.

6. References

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