

An Acoustic Study on Fricative Vowel [i_z] in Zhongwei Chinese

Xinyi Zhang¹, Wen Liu^{1,2}

¹Center for Language Sciences, School of Literature, Shandong University, Jinan, China

²Chinese National Information Technology Research Institute, Northwest Minzu University, Lanzhou, China
z2953356586@163.com, liuwen3214@163.com

Abstract

High vowel fricativization is a common phonetic phenomenon across Chinese dialects. This study investigates the fricative vowel [i_z] in Zhongwei Chinese.

Taking [i_z] in Zhongwei Chinese as the experimental group, [i] and apical vowel [ɿ] in Mandarin Chinese as the control groups, waveforms, spectrograms, formant frequencies, Harmonics-to-Noise Ratio, and vowel charts of [i], [i_z] and [ɿ] were compared. On this basis, this study investigates the acoustic characteristics of [i_z] and the restriction relationship within Zhongwei Chinese syllables. Results show that [i_z] in Zhongwei Chinese is a fricative vowel, which locates at an intermediate stage between [i] and [ɿ] acoustically, relatively closer to [i]. Moreover, there is a highly significant positive correlation between HNR and F2 of [i_z]. As a result, different consonants have evident and various effects on the F2 of [i_z], i.e., the effects of aspirated consonants are more significant than that of unaspirated, and the effects of bilabial plosives and palatals are more significant than that of alveolars.

This study can deepen not only the understanding of [i_z] in Zhongwei Chinese but also the fricative vowels in Chinese dialects.

Index Terms: Zhongwei Chinese, fricative vowel, acoustic analysis

1. Introduction

Zhongwei locates in the midwest of Ningxia province, at the junction of Ningxia, Inner Mongolia, and Gansu province, China. According to *The Language Atlas of China* [2, pp. B1-8], Zhongwei Chinese belongs to the Yinwu dialect area of northern Chinese. Based on linguistic fieldwork, Lin [24, pp. 9-10] pointed out that [i] and [y] in Zhongwei Chinese have apparent friction when articulated. However, due to the absence of experimental evidence, the two vowels have not been explicitly put forward as fricative vowels.

It is a common phenomenon that high vowels ([i] and [y]) are often articulated with severe friction across Chinese dialects. Fricative vowels have already been reported in Wu, Zhongyuan, Jianghuai, Lanyin, and other Chinese dialects [15]. The friction production is the noise source of fricative vowels. Correspondingly, the articulatory mechanism of friction is that the raised tongue position of high vowels leads advection to produce turbulence noise when the airstream passes through the constriction [10][12][18, pp. 137-139][28]. As a result, friction produces, and the Harmonic-to-Noise Ratio (HNR) decreases.

As for resonance characteristics, according to the source-filter theory of speech production, formant frequencies are primarily determined by the size and shape of the vocal tract [5, pp. 15-20][6, pp. 149-153]. Moreover, the place and degree of vocal tract constriction, which is primarily controlled by the position of the tongue, play a significant role in vowel production and differ by vowels [11]. Therefore, the modification to the tongue position triggered by friction can alter the formant frequencies of vowels. And fricative vowels have different resonance characteristics from vowels without friction.

Mainly focused on the degree of friction [1][13][19], previous studies have analyzed the characteristics of fricative vowels through formant frequencies, bandwidths, energy distribution in the frequency domain, HNR, and so on. Besides, Cao [26] and Mai [31] discussed that “[i] with friction” is essentially a laminal vowel between palatal vowel [i] and apical vowel [ɿ], which is seen as “dental approximant [ɿ]” by Lee Kim [23]. Furthermore, combined with traditional and experimental studies, high fricative vowels would finally evolve into apical vowels (e.g., from [i] with weak friction to [ɿ]) [20][21][22][27][28][29], and fricative vowels always lie between Mandarin [i] and [ɿ] acoustically [3][4][7].

There are restrictions within Chinese syllables composed of initials, finals, and tones. And it has already been noticed that different consonants could influence the order of apicalization of vowels; however, these observations were based on traditional phonology rather than acoustic characteristics of vowels [7][27][28]. Based on the great importance of formants in the acoustic analysis of vowels [17, pp. 104-117], it is necessary to compare the formants of vowels in different syllables and reveal the restrictions between consonants and vowels within syllables.

To sum up, though the characteristics of fricative vowels have been investigated for decades, previous studies have mainly focused on the fricative properties of vowels. Few studies have concerned the restrictions within syllables of fricative vowels, which is essential for studying Chinese dialects. Moreover, there are apparent phonetic differences between Zhongwei and other Chinese dialects in the Yinwu dialect area [25, pp. 17-19]. In order to deepen the understanding of fricative vowels across Chinese dialects, it is necessary to make a detailed study of [i_z] in Zhongwei. Based on the above, the research mainly focuses on the acoustic characteristics of [i_z] and the restrictions within Zhongwei Chinese syllables.

2. Methods

There are three kinds of word lists, Zhongwei Chinese [i_z], Mandarin Chinese [i], and [ɿ] (see Appendix 1-3). According

Correspondence to: W. Liu (liuwen3214@163.com).

to Lin [24, pp. 10], there are three lexical tones in Zhongwei Chinese, i.e., a mid-high level tone (T44), a high falling tone (T51) and a low dipping tone (T213). Considering the apparent friction of high vowels mainly occurs as finals alone [20], 85 monosyllabic morphemes with CV structure were selected by referring to *Zhongwei Dialect* [24, pp. 11-20] and listing the minimal pairs. The combinations of phonological units which are non-existent in the Zhongwei Chinese are marked with “—”. Six native speakers of Zhongwei Chinese were recruited (three females and three males, mean age = 31.5 years, standard deviation = 10.81 years). All were non-smokers and did not report any voice problems during the recording.

The recording environment is in a quiet residential room. The software used for recording is *Cool Edit Pro 2.1*, and the sound file format is .wav, with a sampling rate of 22 kHz and 16-bit resolution. Participants were required to read the syllables naturally and comfortably. Each syllable was read twice, with an interval of two seconds, totaling 1020 samples. Then the LPC algorithm was used to extract formant frequencies, *VoiceSauce* was used for HNR parameters, *Excel 2019* for statistics, *Praat*, *RStudio*, and *Excel* for graphics.

3. Results

According to Lin [24, pp. 9-10], [i_z] in Zhongwei Chinese has severe friction from subjective hearing. Furthermore, the articulatory mechanism of friction mentioned above signals that there will be many noise components in the speech signals of fricative vowels. Therefore, waveforms, spectrograms, and HNR of [i_z] and [i] are compared in this section to determine whether [i_z] is a fricative vowel acoustically.

3.1. Friction

In Figure 1, the upper layer of each panel indicates the waveform of steady-state vowel parts in Mandarin Chinese syllables ([i⁵⁵], [ti⁵⁵], [p^{hi}i⁵⁵]) and Zhongwei Chinese syllables ([i_z⁴⁴], [ti_z⁴⁴], [p^{hi}i_z⁴⁴]). Correspondingly, the lower layer of each panel is the spectrogram of Zhongwei and Mandarin syllables. All the syllables are level tones to ensure the stability of phonation.

The waveforms of vowels significantly differ between [i_z⁴⁴] and [i⁵⁵], [ti_z⁴⁴] and [ti⁵⁵], [p^{hi}i_z⁴⁴] and [p^{hi}i⁵⁵]. The arrows in Figure 1 indicate the similar position of the three groups of Zhongwei and Mandarin counterparts. For convenience, the vowels of three group syllables are represented individually by [i] and [i_z] in this section. On the whole, the waveform of [i] in Mandarin is relatively smooth, while the waveform of [i_z] in Zhongwei has lots of subharmonics, which represent the turbulent noise of speech signals [1][19].

Spectrograms can also characterize the friction of [i_z]. In the spectrogram of [i] in Mandarin, the vertical stripes representing glottal pulses are very clear, even in the high-frequency domain, indicating that the noise components of Mandarin [i] are very few. However, when it comes to [i_z] in Zhongwei, glottal pulses and formant structure are extremely vague because of aperiodic noise represented by visible turbulent friction, especially the formants of high-frequency (the black dotted line indicates the F3) [13][14][32]. As a result, [i_z] without consonant and [i_z] after aspirated or unaspirated plosive are obviously fricative. Friction is the inherent attribute of [i_z] in Zhongwei Chinese.

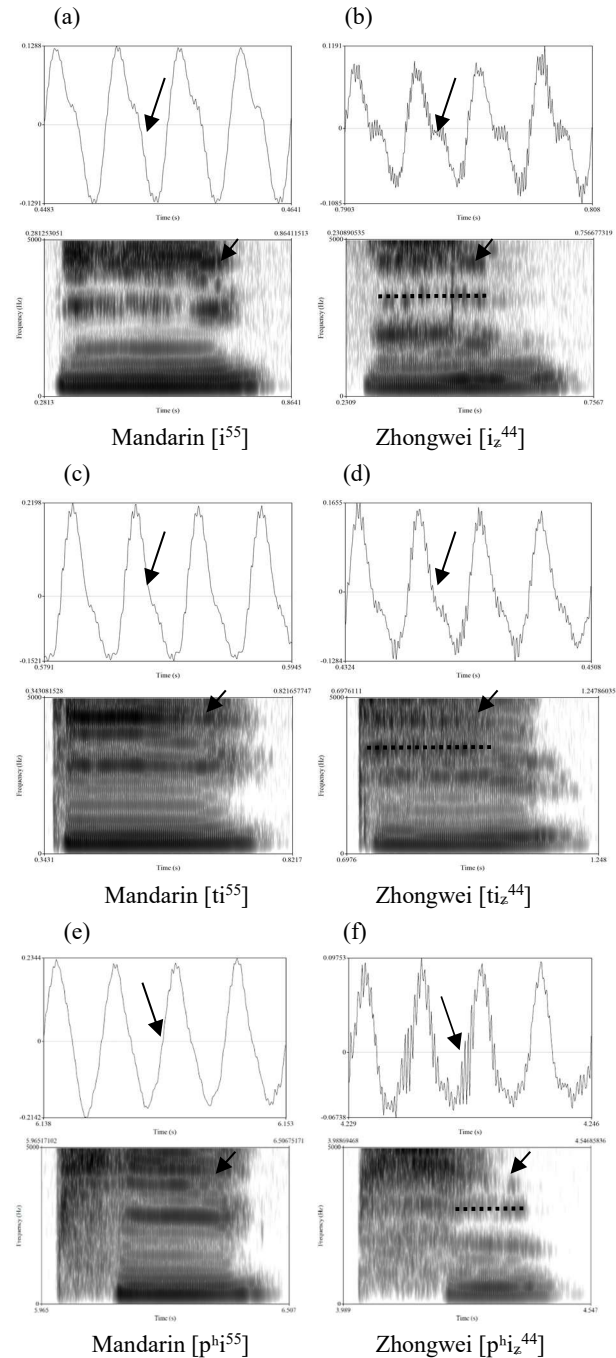


Figure 1: *Mandarin and Zhongwei Chinese Syllables.*

The comparison among waveforms and spectrograms has already shown that there are more noise components in the speech signal of Zhongwei [i_z] than in Mandarin [i]. Besides, it is necessary to quantify further the degree of friction by HNR, which reflects the proportion of noise components in speech signals. The smaller the HNR, the higher the proportion of noise and the higher the degree of friction. As demonstrated in Table 1, [i_z] is characterized by a significantly lower HNR versus [i] ($p < 0.01$), which means the friction of [i_z] is highly severe.

Table 1: Mean and Standard Deviation of HNR (dB).

| Subject | HNR_i (s.d.) | HNR_i _z (s.d.) | P-value |
|---------|--------------|---------------------------|------------|
| F01 | 41.20 (6.13) | 33.99 (5.62) | $p < 0.01$ |
| F02 | 37.89 (4.20) | 34.50 (3.93) | |
| F03 | 37.98 (4.58) | 35.91 (4.83) | |
| M01 | 28.16 (5.00) | 26.61 (4.06) | |
| M02 | 26.36 (5.55) | 22.92 (5.07) | |
| M03 | 26.55 (2.71) | 21.07 (4.84) | |

It is preliminarily determined that the [i_z] in Zhongwei Chinese is a high fricative vowel in nature, which is characterized by the waveforms, spectrograms, and HNR.

3.2. Resonance characteristics

This section explores the acoustic characteristics of the fricative vowels in Zhongwei Chinese by analyzing formants and vowel charts. In Table 2, the F1 and F2 values of [i_z], [i], and [ɿ] are listed. In Figure 2, each ellipse indicates the dispersion of a vowel's 6 data points (6 speakers). Vowel ellipses are drawn with radii of two standard deviations.

Table 2: Mean and Standard Deviation of Formant (Hz).

| | F1 (s.d.) | F2 (s.d.) |
|-------------------------------|----------------|------------------|
| [i] in Mandarin | 324.40 (41.85) | 2496.43 (163.96) |
| [i _z] in Zhongwei | 362.96 (44.78) | 2127.68 (90.23) |
| [ɿ] in Mandarin | 427.40 (53.19) | 1293.74 (164.07) |

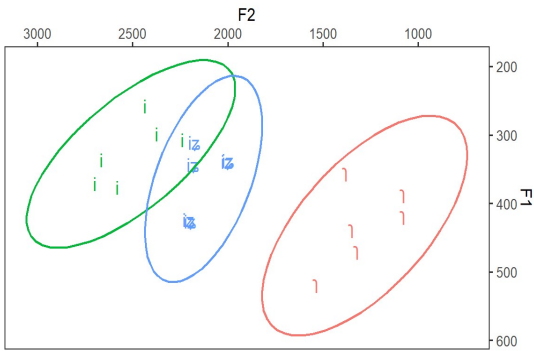


Figure 2: The vowel charts of [i], [i_z], and [ɿ].

The following observations can be summarized according to Table 2 and Figure 2. Firstly, the mean value of F1 is [i] > [i_z] > [ɿ], and there are small differences among them. The mean value of F2 is also [i] > [i_z] > [ɿ]; however, the differences among the three vowels are rather large (over 300 Hz between any two values). Statistical analysis shows that there are significant differences between F1 or F2 of any two vowels among [i_z], [i], and [ɿ] ($p < 0.01$), which indicates that [i], [i_z], and [ɿ] can be well distinguished acoustically. Secondly, the distribution of [i_z], [i], and [ɿ] shows that although the acoustic space of [i_z] locates between [i] and [ɿ], it is closer to the former, even with a little overlap, while the distance between [i_z] and [ɿ] is farther. Thirdly, Shi [20] divided the sound changes of high vowels caused by friction into: [i] without friction → [i] with weak friction → [j] with stronger friction → [z] with strong friction → apical [ɿ]. It is

clear that the deeper the fricative degree, the closer the fricative vowels to the apical vowel. Similarly, as Figure 2 demonstrated, the dispersion degree of ellipses can reflect the differences within the same vowel. [i_z] produced by each speaker differs acoustically, and some of them with larger F1 or smaller F2 are closer to [ɿ]. Thus, it can be concluded that when F1 is larger or F2 is smaller, [i_z] is closer to the apical vowel acoustically.

3.3. Effect of consonants

There are restrictions between initial consonants and finals within Chinese syllables. This section explores the formants variation of [i_z] in different phonological environments.

By controlling all variables except consonants, Figure 3 demonstrates the formant frequencies of [i_z], [i], and [ɿ] in different syllables of each speaker. Three ellipses (95% confidence intervals) represent the acoustic space of the vowels. Compared with Figure 2 and Table 2, the acoustic space of [i_z] significantly expands, especially F2 (s.d. F1 = 49.79; s.d. F2 = 264.11), which reveals the differences of the same vowel [i_z] after different consonants. And the dispersion degree of [i_z] dramatically exceeds that of [i] and [ɿ]. Furthermore, a highly significant positive correlation between HNR and F2 is also observed across consonants ($r = 0.33, p < 0.01$). And, friction is the inherent attribute of [i_z] in Zhongwei Chinese is also demonstrated by Figure 1. Therefore, Section 3.2 and the results above apparently indicate that [i_z] with smaller F2 have a deeper degree of friction. Moreover, we can conclude that various consonants have different effects on the formants of [i_z], especially on F2; the smaller the F2, the stronger the effect and degree of friction.

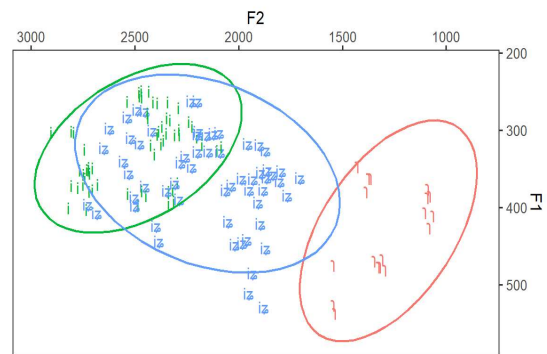


Figure 3: Vowel formants after different consonants.

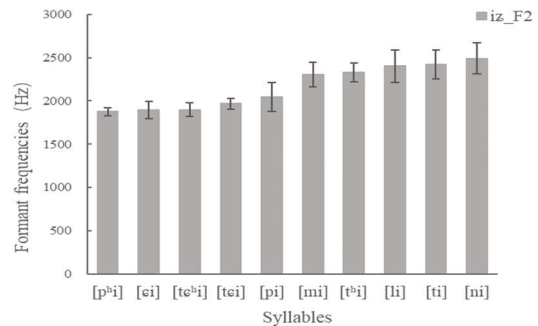


Figure 4: Formants of [i_z] after different consonants.

Figure 4 illustrates the F2 of [i_z] in each syllable. The order of the effect degree of different consonants on F2 can be summarized as follows: bilabial aspirated plosive > palatal fricative > palatal aspirated affricate > palatal unaspirated affricate > bilabial unaspirated plosive > bilabial nasal > alveolar aspirated plosive > alveolar lateral > alveolar unaspirated plosive > alveolar nasal. In conclusion, the highly aspirated or fricative consonants produced with a strong airstream have the most significant effect on the formants of [i_z], such as [t^h], [p^h], and [ç]; The unaspirated plosives and affricates have the medium effect, and the alveolars such as [t] and [l] have a minor effect. Thus, as a result, the effects of aspirated consonants are more significant than that of unaspirated, and the effects of bilabials and palatals are more significant than that of alveolars.

4. Discussion

According to Section 3.3, different consonants have different degrees of effect on friction. This part tries to explain this result from the following perspectives.

For consonants, aspiration (the manner) and the place of articulation affect the following vowel [30]. Firstly, from the perspective of aspiration, as shown in Figure 4, when a pair of consonants have the same manner and place of articulation, F2 of [i_z] after aspirated consonants is lower than that of unaspirated, which indicates that vowels after aspirated consonants usually have more friction. Those consonants have a more substantial influence on the friction of [i_z]. It can be explained that the severe turbulence produced by aspirated consonants can not stop suddenly when vowels onset but continue to affect the following vowels, making the vowels more fricative. Similarly, the affricates and the fricatives also substantially affect [i_z] because of the friction.

Secondly, from the perspective of the place of articulation, F2 of [i_z] after the bilabial plosives is lower. Those consonants have a significant influence on the friction of [i_z]. It can be explained that the bilabial plosives of [p_{i_z}] and [p^hi_z] in Zhongwei Chinese tend to purse lips instead of spreading lips when produced, which lengthen the front cavity of the vocal tract, and decrease the F2 of the vowel that follows (quarter-wave resonators) [6, pp. 153-158][16]. The articulation place of palatals is the anterodorsal of the tongue that contacts or closes to the hard palate to form a blocked or narrow channel for the airstream. In the circumstances, the following vowels are probably assimilated by the consonants [8], so that the tongue positions of [i_z] are raised, and the fricative degree is deepened.

Finally, the F2 of [i_z] after alveolars are all larger, indicating that they have less influence on the friction of [i_z]. It can be explained by the co-occurrence restriction between the alveolar and the high front vowel, which eliminates a potential chance of palatalization [23]. The place of articulation of alveolars is to contact the upper alveolar ridge with the tip of the tongue. It raises the tip of the tongue and lowers the rest part, so that the area of the tongue close to the palate is reduced, which is contrary to the articulatory mechanism of friction. Therefore, the vowels can not be highly fricative.

5. Conclusions

This study draws the following conclusions through acoustic experiments. Firstly, friction is the inherent attribute of [i_z] in

Zhongwei Chinese. The vowel [i_z] is an obvious fricative vowel, which locates at an intermediate stage between Mandarin [i] and [ɿ] acoustically, though it is closer to the former [i]. Secondly, as for restrictions between consonants and vowel [i_z] within syllables, different consonants have different effects on F2 of [i_z]. And there is a highly significant positive correlation between HNR and F2. So the smaller the F2, the stronger the effect. Furthermore, the degree of effect on F2 shows a rank sequence: bilabial aspirated plosive > palatals > bilabial unaspirated plosive > bilabial nasal > alveolars. It is concluded that the rules of effect on F2 are that the effects of aspirated consonants are more significant than that of unaspirated, and the effects of bilabial plosives and palatals are more significant than that of alveolars.

6. Acknowledgments

This work was supported by National Social Science Foundation (22CYY022) and Future Plan for Young Scholars of Shandong University. And we would like to give our thanks to all participants.

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Appendix 1: [i:] in Zhongwei Chinese

| | T1 | T2 | T3 |
|-----------------|-------------|------------|------------|
| ∅ | 衣‘clothes’ | 椅‘chair’ | 意‘meaning’ |
| p | —— | 比‘compare’ | 逼‘force’ |
| p ^h | 批‘refute’ | 皮‘skin’ | 劈‘split’ |
| m | 眯‘squint’ | 米‘rice’ | 蜜‘honey’ |
| t | 低‘low’ | 抵‘resist’ | 地‘ground’ |
| t ^h | 梯‘ladder’ | 题‘topic’ | 剃‘shave’ |
| n | —— | 你‘you’ | 逆‘reverse’ |
| l | 漓‘sporadic’ | 礼‘gift’ | 利‘benefit’ |
| tɛ | 鸡‘chicken’ | 挤‘squeeze’ | 及‘reach’ |
| tɛ ^h | 期‘date’ | 骑‘ride’ | 沏‘infuse’ |
| ɛ | 西‘west’ | 洗‘wash’ | 习‘learn’ |

Appendix 2: [i] in Mandarin Chinese

| | T1 | T2 | T3 | T4 |
|-----------------|-------------|----------|------------|------------|
| ∅ | 衣‘clothes’ | 疑‘doubt’ | 椅‘chair’ | 意‘mean’ |
| p | 逼‘force’ | 鼻‘nose’ | 比‘compare’ | 闭‘close’ |
| p ^h | 批‘refute’ | 皮‘skin’ | 匹‘match’ | 癖‘hobby’ |
| m | 眯‘squint’ | 迷‘fan’ | 米‘rice’ | 蜜‘honey’ |
| t | 低‘low’ | 敌‘enemy’ | 抵‘resist’ | 地‘ground’ |
| t ^h | 梯‘ladder’ | 提‘carry’ | 体‘body’ | 剃‘shave’ |
| n | 妮‘girl’ | 泥‘mud’ | 你‘you’ | 逆‘reverse’ |
| l | 漓‘sporadic’ | 梨‘pear’ | 礼‘gift’ | 利‘benefit’ |
| tɛ | 鸡‘chicken’ | 及‘reach’ | 挤‘squeeze’ | 既‘already’ |
| tɛ ^h | 期‘date’ | 骑‘ride’ | 起‘get up’ | 沏‘infuse’ |
| ɛ | 西‘west’ | 习‘learn’ | 洗‘wash’ | 细‘thin’ |

Appendix 3: [ɿ] in Mandarin Chinese

| | T1 | T2 | T3 | T4 |
|-----------------|----------|---------|---------|----------|
| ts | 滋‘grow’ | —— | 子‘son’ | 自‘self’ |
| ts ^h | 龞‘grin’ | 词‘word’ | 此‘this’ | 次‘order’ |
| s | 思‘think’ | —— | 死‘die’ | 四‘four’ |