Tone 4 Sandhi in Heze Chinese

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We present in this paper an acoustic study of the base tones and Tone 4 sandhi in Heze Chinese, a Mandarin dialect. By conducting two tasks, we investigate the four base tones in Heze Chinese and the Tone 4 sandhi patterns. Our results show overall similar characteristics to previous studies, but we find that Tone 2 in Heze Chinese has a short rise before a long fall, instead of a straight fall. The remaining tones are falling-rising contour tones (Tones 1 and 4) and a flat Tone (Tone 3). We argue that Tone 4 sandhi in Heze Chinese has three patterns: the Tone 4 contour changes to falling when it is followed by Tone 1 and Tone 3, the contour stays the same when it is followed by Tone 2, and the contour inflection point moves forward when it is followed by another Tone 4.
Keywords: tones, tone sandhi, Heze dialect, Standard Mandarin

1. Introduction

Tone is widely used in many African and Asian languages to make lexical contrast. Chinese dialects in particular are known for their complex tone patterns. Previous acoustic studies of Chinese tone patterns have mainly focused on a specific set of Chinese varieties or dialects, for example, the dialects of Beijing (Ping, 2006), Tianjin (Zhang & Liu, 2011; Zhang, 2014), Shanghai (Zhu et al., 1995), Wuxi (Chen, 2000), and Chengdu (Lin, 2006), as well as Taiwanese Mandarin (Peng, 1997). However, Chinese dialects consist of 7 to 10 dialectal groups (Tang, 2018), and even within Mandarin Chinese alone, there are eight subgroups (Wurm et al., 1987). Thus, it is the case that

most Chinese dialects are understudied in terms of tone patterns. Heze Chinese is one such case. In this paper, we present an acoustic study of the tonal inventory and Tone 4 sandhi patterns of Heze Chinese.

Heze is the westernmost city of Shandong province and is located at the meeting point of four provinces (Shandong, Henan, Anhui, and Jiangsu). According to the *Language Atlas of China* (Wurm et al., 1987), the Heze Dialect belongs to the Zhengcao dialect of Zhongyuan Mandarin, which has more than 10 million speakers. Although the consonant and vowel inventories of Heze Chinese have some differing characteristics, they both fall within the northern Mandarin system. However, the tonal inventory is a different case, being the main difference between it and other nearby varieties.

Like Standard Mandarin, Heze Chinese has four tones (indicated as Tone 1-Tone 4). However, its pitch values are different, and it has a considerably more complex pattern of tone sandhi (Jiang, 2016; Yang, 2015). Previous synchronic studies of Heze Chinese have mainly focused on description, including the recording of vocabulary and proverbs. For example, Yang (2015) analyzed the disyllabic tone sandhi of Heze Chinese within Optimality Theory, and Jiang (2016) systematically described the sounds of two districts and eight counties of Heze. However, both papers provide only a description of the base tone and tone sandhi systems in this variety. Therefore, we use experimental methods to explore the four tones of Heze Chinese first; then we focus on Tone 4, which is hypothesized to be a contour tone, to observe its tone sandhi patterns when it combines with each base tone. This tone was chosen due to the fact that its sandhi was previously discussed in Jiang (2016) and Yang (2015), and analyzing all tone sandhi patterns would be too much for one paper.

The rest of the paper is organized as follows. We start with a review of the literature on Mandarin tone sandhi, with particular focus on Heze Chinese. We then move to our study of the base pitch values and Tone 4 sandhi in Heze, starting with the method and experiment design and followed by the results of two tasks. The following section discusses implications for theory and methodology. Finally, the last section provides concluding remarks and points to directions for future research.

2. Literature Review

2.1 Tones in Standard Mandarin and the Heze Dialect

We use Chao's (1948, 1965) five-level tone system to differentiate tone values, where 1 is the lowest possible tone and 5 is the highest possible tone. The tones of Standard Mandarin are [55] for Tone 1, [35] for Tone 2, [214] for Tone 3, and [51] for Tone 4 (Duanmu, 2007). As a Mandarin dialect, the tones of Heze Chinese correspond to those of Mandarin; however, they surface differently. Table 1 compares the tones of Standard Mandarin with the findings in previous studies of Heze tones (Jiang, 2016; Yang, 2015). We use 'H' to represent a high tone, 'M' to represent a mid tone, and 'L' to represent a low tone.

While Tone 1 in Standard Mandarin is a high flat tone (also called 'level'), both previous studies determined that it is a contour tone [213] in Heze. Tone 2 is a rising tone in Standard Mandarin, but both previous studies classify Tone 2 as high falling in the Heze dialect. While Jiang (2016) classifies Tone 2 as [53], Yang (2015) classifies it as [52]. Tone 3 in the Heze dialect was determined to be high flat in the previous studies, being [55] in Yang (2015), identical to Tone 1 in Standard Mandarin, and [44] in Jiang

Table 1

Tone representations of Standard Mandarin and the Heze Dialect in previous studies

	Tone 1	Tone 2	Tone 3	Tone 4
Standard Mandarin (Duanmu, 2007)	HH [55]	MH [35]	LLH [214]	HL [51]
Heze Dialect (Jiang, 2016)	LLM [213]	HL [53]	HH [44]	MLL [312]
Heze Dialect (Yang, 2015)	LLM [213]	HL [52]	HH [55]	HLL [412]

(2016). Meanwhile, Tone 3 is a contour tone in Standard Mandarin. Tone 4 is described as a contour tone in the Heze dialect by both previous studies, as opposed to a falling tone in Standard Mandarin. The contour of Tone 4 in Heze, described as [312] by Jiang (2016) and [412] by Yang (2015), is very similar to Tone 1.

As we can see in Table 1, both Jiang and Yang's systems have the same pattern for each tone, assigning two contour tones, Tone 1 and Tone 4, one falling tone, Tone 2, and one flat tone, Tone 3. However, small differences exist between the two descriptions of Tones 2, 3, and 4.

2.2 Tone Sandhi in Chinese Dialects

Tone sandhi refers to a phonological alternation that occurs when tones come into contact with each other. Studies of historical Chinese phonology show that Chinese tone sandhi could date back thousands of years, and the historical processes of splits and mergers have given rise to a wide variety of tonal systems in the modern dialects of Chinese (Cheng, 1973; Chen, 1976, 2000; Mei, 1977). Ultimately, the sandhi patterns vary a lot across Standard Mandarin and the different Mandarin dialects.

Tone sandhi in Chinese can be classified into two types based on the different operation methods (Chen, 2000; Hyman & VanBik, 2004). The first type of tone sandhi is

sensitive to morphosyntactic structure. Beijing Mandarin is representative of this tone sandhi type. In this type, tone sandhi applies from the inner morphosyntactic constituent outwards. Thus, the direction of rule application is generally governed by morphosyntactic structure. Another type of tone sandhi is directional tone sandhi. In this type, morphosyntactic structure has no effect on tone sandhi. In these dialects, tone sandhi operates left to right while in others it operates right to left (Lin, 2006). Many Mandarin dialects, such as Tianjin Chinese (Chen, 2000; Zhang & Liu, 2011), Chengdu Chinese (Lin, 2006), and Boshan Chinese (Lin, 2004), display this type.

It is worth noting that most of the previous studies have focused only on the dialects mentioned above and tried to interpret the tone patterns within particular theories. For example, Lin (2006) examined tone sandhi in Chengdu and revealed some interesting properties of tone sandhi directionality. For example, in tritonal strings, both directions of tone sandhi are accepted, but in quadritonal strings, unlike tritonal, a sensitivity to morphosyntactic structure appears.

Shi and Wang (2004) recorded disyllabic words with the four sandhi combinations from 204 Tianjin speakers and investigated differences among age groups in 10-year increments for their application of sandhi. Their study reveals that there is a shift in tone sandhi patterns between old and young speakers. For instance, younger speakers had a higher percentage of Tone 1 sandhi than older speakers, and Tone 4 + Tone 4 sandhi had generally disappeared from younger speakers. These findings show that Tianjin Chinese has been affected by Standard Mandarin sandhi.

Zhang and Liu (2011) conducted an acoustic study of tone sandhi and tonal coarticulation in Tianjin Chinese. Their results also highlight Standard Mandarin's effect

on the dialect, but they also show that the majority of the sandhi patterns are non-neutralizing. Additionally, they investigate tonal coarticulation in Tianjin. The study reveals the existence of progressive assimilation, regressive dissimilation, a greater progressive effect, and a number of High/Low asymmetries.

These studies show some trends in Chinese tone sandhi. First, Chinese tone sandhi is complex and would be very difficult to explain within a single theory. Second, tone sandhi in different Chinese dialects has been affected by Standard Mandarin to some degree. Third, due to dialectal contact and the effect of Standard Mandarin, the productivity of Chinese tone sandhi patterns is influenced by both categorical factors, such as phonological opacity, and gradient factors, such as the phonetic nature and frequency of usage of the specific sandhi pattern (Zhang & Liu, 2011). Faced with these issues, Zhang (2010) points out that it is necessary to "cultivate a new respect for empirical data based on well-designed phonetic and psycholinguistic studies" (p. 1137). However, we also see that most Chinese dialects are understudied in terms of well-designed phonetic experiments. Therefore, it is necessary to implement studies to document the tone patterns of these low-resource languages. With little work on its instantiation of tone, and the existing work showing that Heze tones differ from Standard Mandarin, the Heze dialect is an ideal choice for investigating tone patterns in low-resource Chinese dialects.

2.3 Tone Sandhi in the Heze Dialect

Based on Section 2.1, disyllabic words in Heze Chinese have 16 possible tone patterns or combinations if we do not take the neutral tone into consideration. To keep the scope of the study narrow, we focus only on Tone 4 sandhi in disyllabic words. Jiang

(2016) and Yang (2015) have described this sandhi using different methods of representation, and as shown in Table 2, when Tone 4 is followed by Tone 1, Tone 2 or Tone 3, the contour of Tone 4 changes to a falling tone, and when a Tone 4 is followed by the other Tone 4, the contour in the first Tone 4 changes to a contour like Tone 1. However, we do not know how the previous studies arrived at the provided pitch values since they did not provide any information regarding their methods. We, thus, examine acoustic measurements of the four tones and Tone 4 sandhi in the current study.

The previous research on the Heze Dialect has found the following regarding tone sandhi. In Jiang's study, there are six patterns that have tone sandhi, including when a falling tone is followed by a Tone 4, the falling tone changes to a flat tone. However, in Yang's analysis, there are eight sandhi patterns. Taking Tone 4 as an example, it seems that the descriptions from the two papers are quite similar. When Tone 4 is followed by Tone 1, Tone 2, and Tone 3, the contour disappears. When Tone 4 is followed by another Tone 4, Yang indicates that the HLL becomes LM, while Jiang states that MLL becomes LLM. Note that these studies did not suggest any universal directionality of tone sandhi application in the Heze dialect. However, these particular instances of sandhi are right to left.

While both previous studies consider Tone 4 to become a falling tone in many cases of sandhi, they differ slightly in how they classify this sandhi precisely. For the cases where Tone 1, Tone 2, or Tone 3 follow Tone 4, Jiang (2016) considers Tone 4 to be

Table 2

Tone 4 sandhi in the Heze dialect as descried in Jiang (2016) and Yang (2015)

	Tone 4+Tone 1	Tone 4+Tone 2	Tone 4+Tone 3	Tone 4+Tone 4
Jiang (2016)	312→31	312→31	312→31	312→213
Yang (2015)	HLL→HL	HLL→HL	HLL→HL	HLL→LM

[31], but Yang (2015) considers it to be HL. For two adjacent Tone 4s, the first is considered to be LM and rising by Yang (2015) but only a slightly different contour [213] by Jiang (2016).

3. Questions and Hypotheses

In this paper, we aim to address the following questions:

1. What are the four basic tones in the Heze dialect, and how do they compare to the tones of Standard Mandarin and the previous work by Jiang (2016) and Yang (2015)?
2. How does Tone 4 sandhi affect the tones of the first syllable of disyllabic tokens in the Heze dialect, and how does this compare to the sandhi findings in Jiang (2016) and Yang (2015)?

To answer these questions, we developed two tasks. In the first task, subjects were presented with slides containing one monosyllabic word at a time. They were asked to read the words as they appeared on the screen. The second task followed the same structure, but each slide contained disyllabic words.

We began with the hypothesis that the four tones in the Heze dialect are as follows: Tone 1 (rising [25]), Tone 2 (falling [51]), Tone 3 (mid-high flat [44]), and Tone 4 (contour [423]). This prediction is based on the findings of Jiang (2016) and Yang (2015), as well as self-analysis by one of the authors, a native speaker of the dialect. The key difference in this hypothesis compared to the previous work is that the native speaker author did not believe that a short fall was occurring in Tone 1. Based on the conclusions

of the previous studies and our hypotheses for the monosyllabic tones, we hypothesized that Tone 4 becomes a [42] falling tone before Tone 1, Tone 2, and Tone 3. In the case of two adjacent Tone 4s, we hypothesized that the first Tone 4 remains largely unaffected at [423], with potentially a slightly higher [3] at the end to meet the [4] at the beginning of the following tone.

4. Method

4.1. Speakers

A total of 10 speakers of Heze Chinese (six female, four male) participated in the experiment. All speakers were from the inner-city district of Heze, known as the Mudan District. Specifically, they were all born in the Mudan District, their parents were both from the Mudan District, and they spent no more than one year living outside Heze. The average age of the 10 speakers was 20.6 years, and the age distribution is as follows: 19 (n=1); 20 (n=5); 21 (n=1); 22 (n=3), with approximate birth years 1997 to 2000. All speakers were students at Heze University at the time of recording, and none reported any language impairments or cognitive disabilities. All such information about the speakers was obtained using a questionnaire-style survey.

4.2. Stimuli Design

In the first task, we used 32 monosyllabic characters to examine the basic tone pitches. We made eight groups of four characters, with one being from each base tone so that there was no overlap. The characters were chosen with consideration of Jiang's (2016) conclusion that the tones in Heze map to the tones of Standard Mandarin. In order to make sure all the characters matched the expected tones, we conducted a pilot study

Table 3

Monosyllabic stimuli used in task 1

	Char	IPA	Gloss		Char	IPA	Gloss
Tone 1	中	[tʂuŋ]	'middle'	**Tone 2**	人	[ʐən]	'person'
	川	[tʂʰuɑn]	'river'		和	[xə]	'and'
	光	[kuɑŋ]	'light'		来	[lɑi]	'to come'
	新	[ɕin]	'new'		年	[njɛn]	'year'
	昌	[tʂʰɑŋ]	'flourishing'		元	[ɥɑn]	'yuan'
	播	[puə]	'broadcast'		从	[tsʰuŋ]	'from'
	声	[ʂəŋ]	'sound'		才	[tsʰɑi]	'just'
	天	[tʰjɛn]	'sky'		明	[miŋ]	'bright'
	Char	**IPA**	**Gloss**		**Char**	**IPA**	**Gloss**
Tone 3	普	[pʰu]	'general'	**Tone 4**	后	[xoʊ]	'back'
	打	[ta]	'to hit'		面	[mjɛn]	'surface'
	网	[uɑŋ]	'net'		靠	[kʰɑʊ]	'to lean'
	懂	[tuŋ]	'understand'		梦	[məŋ]	'dream'
	搞	[kɑʊ]	'to do'		近	[tɕin]	'near'
	写	[ɕjɛ]	'to write'		换	[xuɑn]	'to change'
	有	[joʊ]	'to have'		带	[tɑi]	'to take'
	展	[tʂɑn]	'exhibition'		位	[uei]	'position'

Note: Char = Character

with two native speakers of Heze Chinese. The monosyllabic stimuli are provided in Table 3.

In the second task, we used disyllabic words to examine Tone 4 sandhi. We created four groups of stimuli, each of which contained four disyllabic words in the contexts of Tone 4+Tone 1, Tone 4+Tone 2, Tone 4+Tone 3, and Tone 4+Tone 4. The choice to observe right-to-left sandhi application was based on the fact that this was the directionality observed by Jiang (2016) and Yang (2015). Furthermore, two additional

disyllabic words were added to each group as distractors, resulting in a total of 24 words per speaker. We selected words from a balanced corpus for Mandarin built by the State Language Commission[1], where the frequencies were determined from texts containing 20 million tokens across all genres. In each group, two words with comparatively higher frequencies and two words with lower frequencies were selected. To make sure all the words contained the expected tones, we used the pilot study described for the first task. The disyllabic stimuli are provided in Table 4 below. The glosses and characters for the disyllabic stimuli are provided in the appendix.

Overall, the produced corpus consists of 32 monosyllabic and 16 disyllabic target tokens per speaker, resulting in a total of 480 tokens. Split by tone, there are 8 monosyllabic tokens per tone per speaker and 4 disyllabic tokens per tone pattern per speaker.

Table 4
Disyllabic stimuli

T4+T1	IPA	Pinyin	Frequency	T4+T2	IPA	Pinyin	Frequency
A	[ti.tɕʰy]	dì.qū	0.0481	A	[ti.tɕʰjou]	dì.qiú	0.0216
B	[sz.tʂʰuɑn]	sì.chuān	0.0045	B	[nei.ʐuŋ]	nèi.róng	0.0393
C	[ɕin.fəŋ]	xìn.fēng	0.0006	C	[tsɑʊ.tʂʰuɑn]	zào.chuán	0.0006
D	[ʂou.tsɑi]	shòu.zāi	0.0006	D	[fei.jɑn]	fèi.yán	0.0007
T4+T3	IPA	Pinyin	Frequency	T4+T4	IPA	Pinyin	Frequency
A	[xɑn.y]	hàn.yǔ	0.0058	A	[yn.tuŋ]	yùn.dòng	0.0529
B	[tjɑn.jŋ]	diàn.yǐng	0.0077	B	[tjɑn.xuɑ]	diàn.huà	0.0086
C	[xuɑ.tʂɑn]	huà.zhǎn	0.0006	C	[tɕiŋ.tjɛn]	jìng.diàn	0.0008
D	[tʂʰou.jɑŋ]	chòu.yǎng	0.0006	D	[ʂə.luən]	shè.lùn	0.0008

[1] Corpus accessed in 2019 at http://www.cncorpus.org/.

4.3. Experimental Procedure

At the beginning of the testing session, each participant was asked to complete a questionnaire containing ten questions. The questions were related to participant gender, age, and general information about his/her hometown. The questionnaire was designed to take 5 minutes to complete.

After completing the questionnaire, participants completed the recording. The tokens were presented in randomized order and presented on individual slides. In order to prevent participants from reading too fast, only one token was presented on each slide so that the time to change slides would prevent tokens from running into each other. To help participants adjust recording devices to their own testing conditions, a familiarization test was done before the real recording. The participants were under the supervision of a faculty member at Heze University who knows one of the authors. The recordings were conducted in a quiet room at the university to guarantee the tasks were completed as expected. All recordings were saved as WAV files, with a separate file for each task, resulting in two files per participant. Participants recorded themselves on their own personal computers.

4.4. Data Analysis

Acoustic analysis of the data was conducted in *Praat* (Boersma & Weenink, 2024). Additionally, we used Xu's (2013) *Praat* script *ProsodyPro* to measure f_0 for each syllable. In *ProsodyPro*, time-normalization is the key method to facilitate close analysis of continuous f_0 contours over multiple tokens. It can smooth out random variations unintended by the speaker as well as individual differences, leaving only consistent variations due to tone and contextual tonal variations (Xu, 2013). Before annotating the

tone boundaries, we set the pitch range to 75 to 396 Hz for male speakers and 130 to 396 Hz for female speakers. We then annotated the tone boundary for each syllable, ran the script, and got 10 points per interval for each syllable with the f_0 values. The tone of each syllable was thus represented as a 10-dimension vector.

The normalized tone intervals 0-1, 1-2, 2-3, 3-4, and 4-5 correspond to the 1-5 scale in Chao's (1948, 1965) tone system, respectively. For each speaker, the normalized f_0 value at each of the 10 points was calculated with Shi's (1986) normalization equation (1), where $f_{0\,min}$ and $f_{0\,max}$ refer to the minimum and maximum f_0 values in Hertz in that speaker's averaged f_0 data for the four tones. After normalization, all data points fall within the 0-5 range. All figures in this paper are plotted with this normalized f_0.

(1) $$f_{0\,normalized} = 5 \times \frac{log_{10}(f_0) - log_{10}(f_{0\,min})}{log_{10}(f_{0\,max}) - log_{10}(f_{0\,min})}$$

5. Results

5.1. Estimated Tone Distribution

To visualize the relative distribution of the tones in a two-dimensional space, we took the average normalized tones across the corpus for all speakers and plotted them as four points on an *xy*-coordinate plane. The *x*-value of each point represents the starting point of a tone, and the *y*-value represents the end point. This representation helps visualize the start and end points of each tone and how they compare with one another. As shown in Figure 1 below, Tone 2 and Tone 4 are quite close to each other in the right bottom corner. This indicates that both tones started with a higher pitch and ended with a lower pitch, with the end of Tone 2 being a little bit higher than the end of Tone 4. Meanwhile, Tone 1 ended slightly higher than it started, and Tone 3 ended notably higher

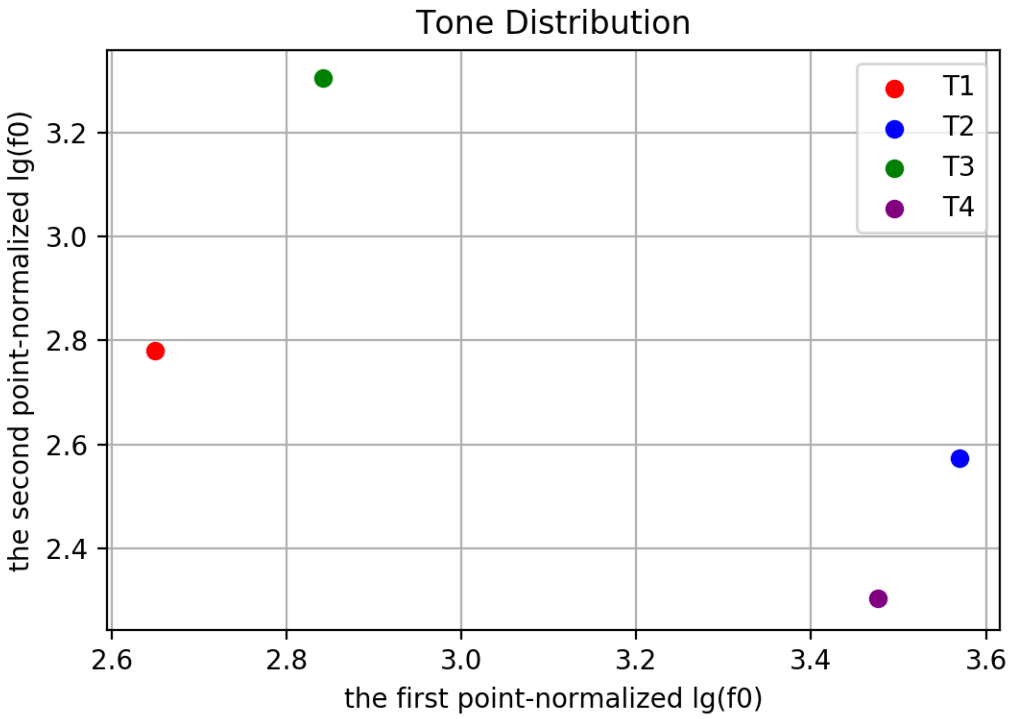


Figure 1
Estimated distribution of the start and end points of each tone.

than it started. While this graph is good for visualizing the start and end points of the tones, it does not allow us to see any contours. For example, in this graph, Tone 1 appears to be a flat tone because its start and end are almost equal. However, in reality, it is a contour tone.

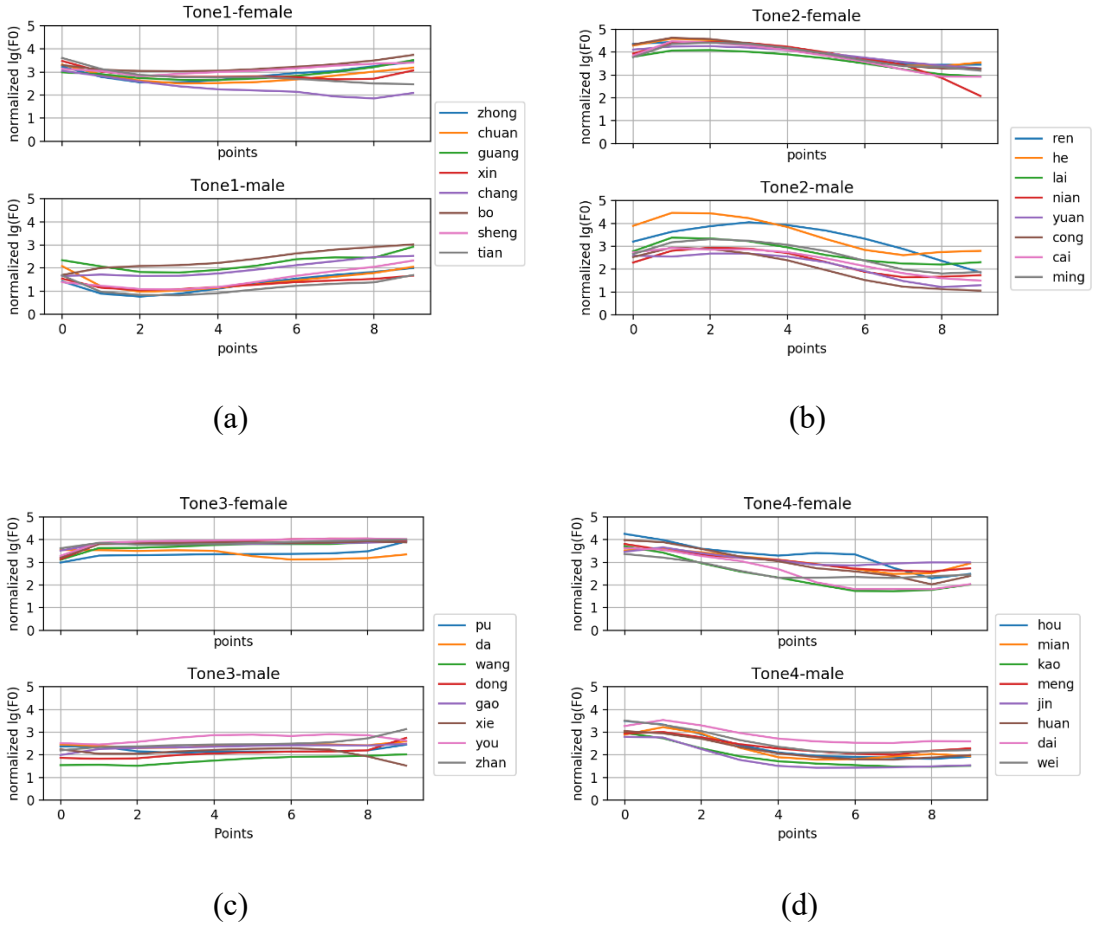
5.2. Monosyllables

Figure 2 below gives the normalized f_0 averages by token for the four tones, with female and male speakers plotted separately. Figure 2a shows a pronounced concave contour for Tone 1 in both female and male speakers. The Tone 1 of female speakers starts from a mid-high f_0 onset, goes down to mid, then rises back up to mid-high, while male speakers start from a mid-low f_0 onset, go down to low, then rise up to mid. Figure 2b shows Tone 2, which is also a contour, but it is convex. Female speakers start from a

mid-high f_0 onset, rise up to high, then go down to mid, while male speakers start from mid, rise to mid-high, then go down to low. Figure 2c shows Tone 3, which is a flat tone, mid-high for female speakers and mid-low for male speakers. Figure 2d shows Tone 4 as a concave contour, similar to Tone 1 but starting higher and ending lower. Female speakers start from a mid-high f_0 onset, go down to mid-low, then tend to rise to mid at the very end, while male speakers are lower than the female speakers. Table 5 gives the average of the four tones separated by gender.

Figure 2

Average normalized f_0 of 32 syllables classified by tone



Note: The upper figure for each tone indicates the tone patterns of female speakers and the lower indicates the tone patterns of male speakers.

Table 5
The four basic tones in Heze

	Tone 1	Tone 2	Tone 3	Tone 4
Female	mH-M-mH [434]	mH-H-M [453]	mH-mH [44]	mH-mL-M [423]
Male	mL-L-M [213]	M-mH-L [341]	mL-mL [22]	M-L-mL [312]

Ultimately, Tone 1, Tone 3, and Tone 4 generally have the same pitch pattern as the findings in previous research, although the specific values are different. However, Tone 2 shows a different picture, as it was described as a falling tone in previous research, but our results indicate a convex contour.

For a general view of the four basic tones in Heze Chinese, Table 6 and Figure 3 give the average for each tone regardless of gender. Note that taking the average has reduced the fluctuation in the tones, so they all range between mid-high and mid-low. Although Tone 1 and Tone 4 are both concave contour tones, they are not the same. Tone 1 has a short fall and a long rise, but Tone 4 has a long fall and a short rise.

Figure 3
Average normalized f_0 of each tone over all tokens and speakers

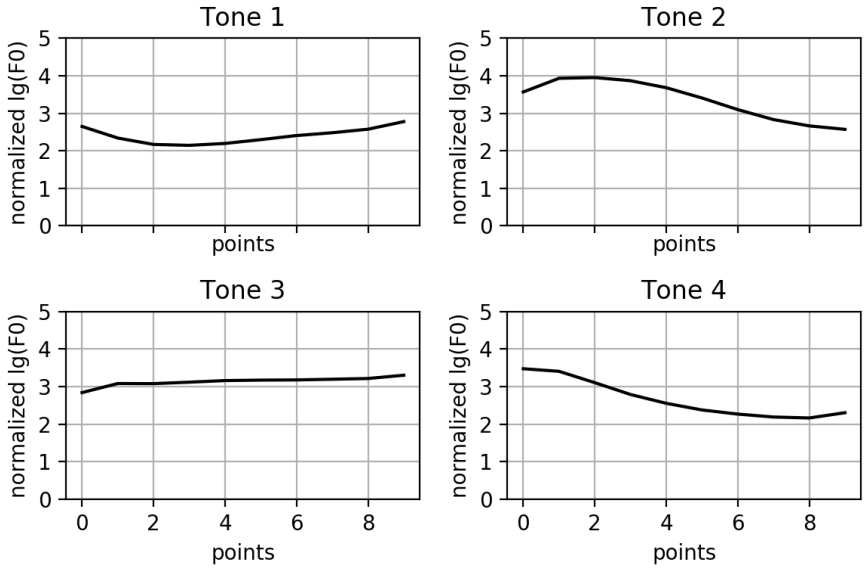


Table 6
Four base tones with averaged normalized f_0

	Tone 1	Tone 2	Tone 3	Tone 4
average	M-mL-M [323]	M-mH-mL [342]	M-M [33]	mH-mL-M [423]

5.3. Disyllabic Tones - Tone 4 Sandhi

As already shown in Table 2, previous research has indicated that Tone 4 sandhi in Heze Chinese has two outcomes. When a Tone 4 is located before a Tone 1, Tone 2, or Tone 3, the short rise at the end of the Tone 4 is deleted. Meanwhile, a Tone 4 simply changes its contour shape when it is followed by another Tone 4, resulting in a contour similar to Tone 1.

Figure 4 gives the normalized f_0 averages by token for the four tones, with females and males plotted separately. The labels a, b, c, and d correspond to the tokens labelled as such in Table 4. 4a shows tones produced by female speakers and 4b shows tones produced by male speakers. For both female and male speakers, when Tone 4 is followed by Tone 1 and Tone 3, the short rise is missing. When the following syllable is Tone 2, in order to rise up to Tone 2, which should start from mid-high, the contour tail in the initial Tone 4 remains. The most prominent change happens in the Tone 4+Tone 4 pattern, in which the initial Tone 4 is still a contour but has an obvious change.

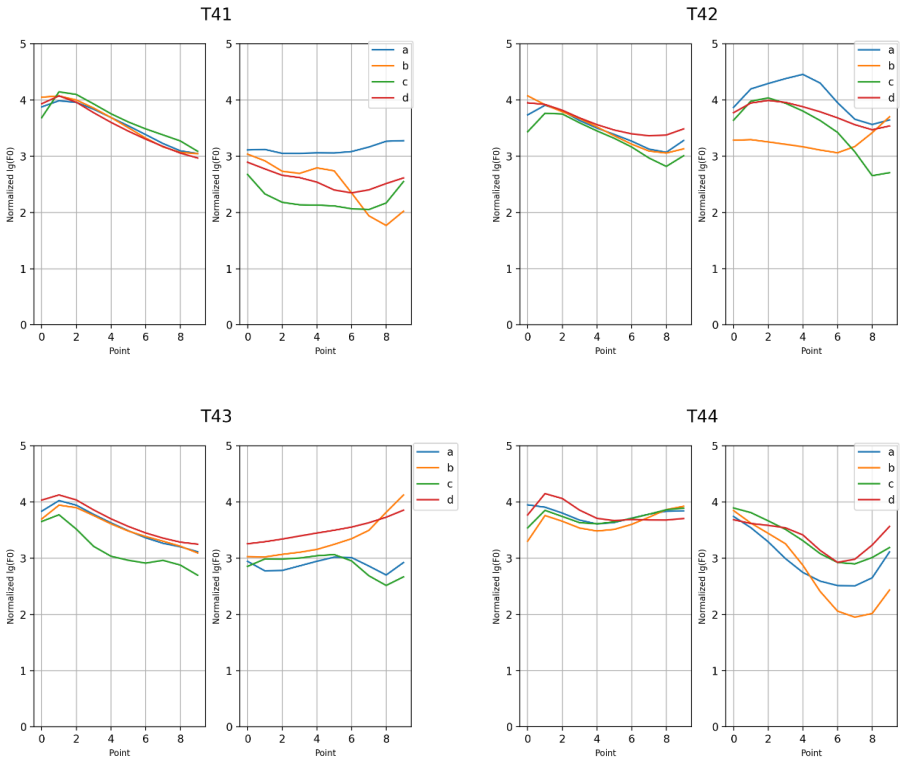


Figure 4a

Normalized Tone 4 sandhi over time for female subjects split by token

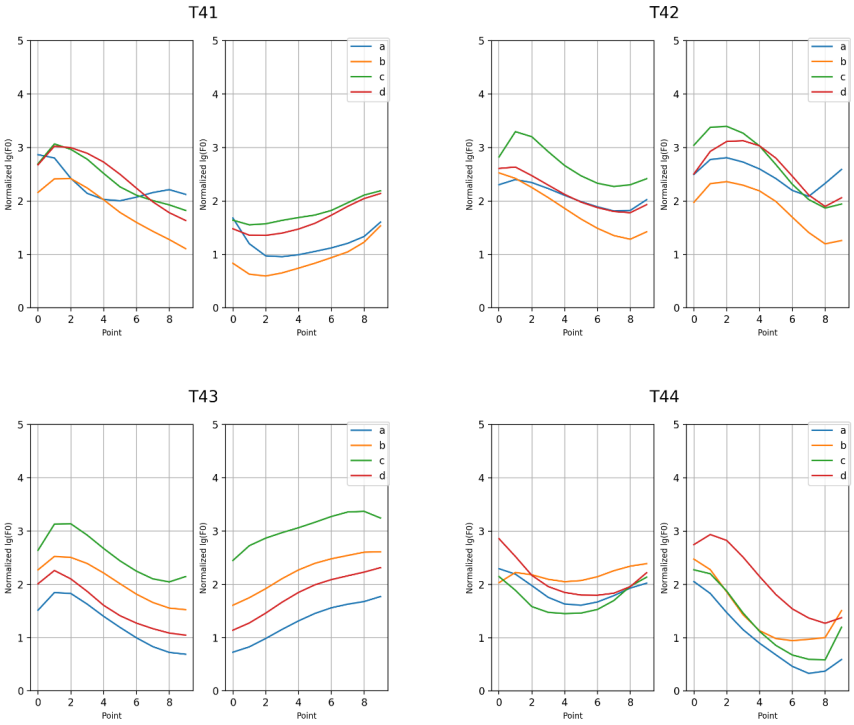


Figure 4b

Normalized Tone 4 sandhi over time for male subjects split by token

Figure 5 below averages the sandhi patterns on the disyllabic tokens for all participants and plots them with the monosyllabic tone patterns. Figure 5 further verifies the results in Figure 4. It is clear that in the Tone 4+Tone 1 and Tone 4+Tone 3 patterns, the contour tone changed to a straight falling tone. In the Tone 4+Tone 2 pattern, the contour tone stayed. Meanwhile, in the Tone 4+Tone 4 pattern, the first Tone 4 reduced its degree of curve and changed its contour position. A single Tone 4 has a long fall, a short rise, and an inflection point located near the end, but in disyllabic words the first Tone 4 moved its inflection point forward, resulting in a short fall and a long rise, which is very similar to Tone 1. Table 7 summarizes these results.

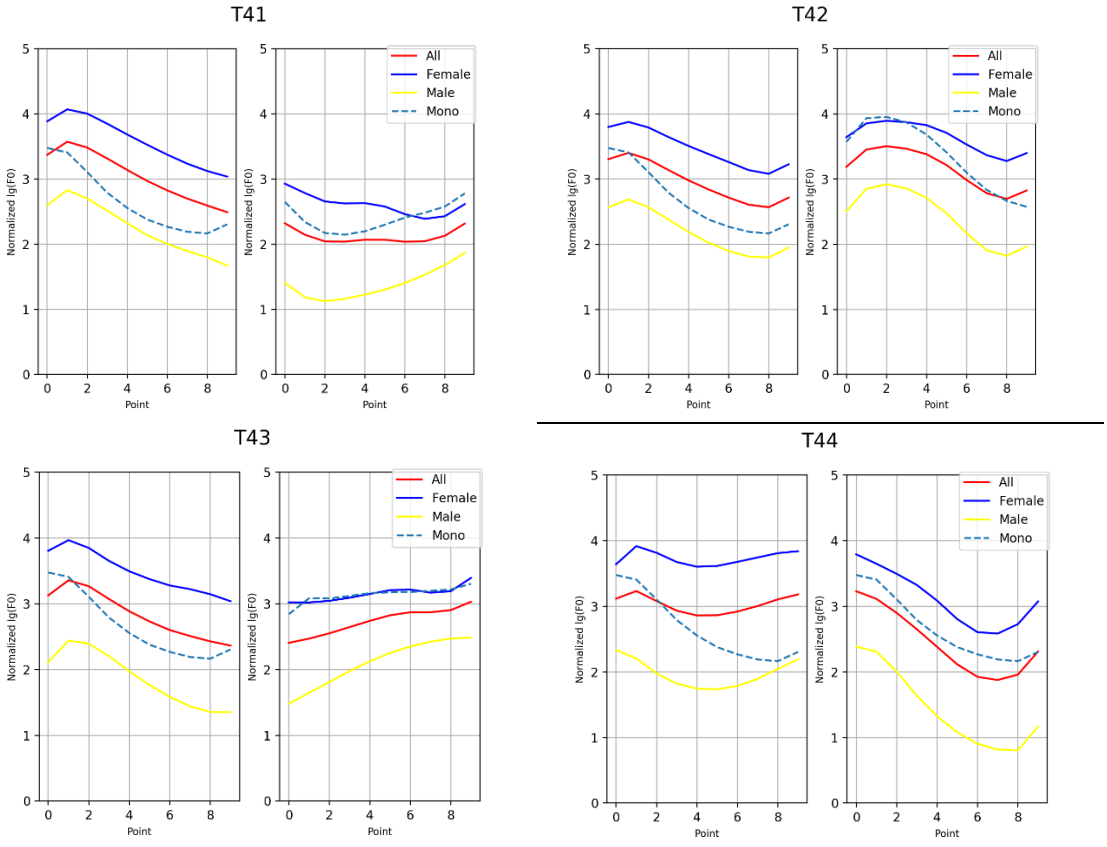


Figure 5

Average normalized f_0 of the four sandhi patterns by gender and by all participants

Table 7

Tone 4 after sandhi application

Tone 4+X	X=Tone 1	X=Tone 2	X=Tone 3	X=Tone 4
Tone 4	**mH-mL (42)**	mH-mL-M (423)	**mH-mL (42)**	**M-mL-M (323)**

Note: Bold text indicates sandhi

6. Discussion

When combining all the participants together, the tones all fall within the mid-low to mid-high range, which is a smaller range than what was found in previous studies on the Heze dialect. Additionally, compared with previous research, the Tone 4 contour in this study is not prominent, and Tone 2 in this study is not a falling tone, but a rising-falling contour.

In the case of Tone 4 sandhi, our findings differed slightly from the previous work done on the Heze dialect. Before Tone 1, Tone 2, and Tone 3, Tone 4 was found to become 31 by Jiang (2016) and HL by Yang (2015). Our data suggests that Tone 4 becomes 42 prior to Tone 1 and Tone 3, still falling but slightly different from the previous findings. There appears to be no sandhi when preceding a Tone 2, with Tone 4 still surfacing as 423. In the case of two adjacent Tone 4s, Jiang (2016) found there was a slightly altered contour of 213 in the first Tone 4 while Yang (2015) found the first Tone 4 was rising LM. Our findings agree that the first Tone 4 is still a contour; however, the values are different at 323.

There are several possible reasons for the differences between the findings in this study and the findings of previous studies. The first reason is influence from Standard Mandarin. If we further divide Heze Chinese based on age group, it can be split into a newer variety spoken by the younger generation and an older variety spoken by the older

generation. As mentioned previously, the average age of the ten participants is 20.6 years old. In contrast, the participants in Jiang's (2016) experiment were all over 60 years old. The younger generation is exposed to Standard Mandarin more than the older generation due to being required to speak it in school and exposure to it through social media. As a result, they spend less time speaking Heze Chinese than the older generation. Furthermore, our results suggest that Tone 4 in Heze Chinese is trending toward assimilation with Tone 4 in Standard Mandarin, which is a high-low falling tone, as the Tone 4 contour was not very strong in our data.

The second possible reason for divergence from previous findings is the syllable structure of our stimuli. In our study, we did not consider syllable structure when selecting stimuli characters or words. We are not sure whether tones over Consonant + Vowel structures would be different from those over Consonant + Vowel + Nasal Coda structures. Third, variation in the rate at which the speakers read the stimuli could have influenced the results as well.

Furthermore, it is worth noting that previous studies have not used experimental tools like *Praat* to document tone patterns. Since previous studies did not offer detailed documentation of the fundamental frequency, they could have lost information during description. For instance, in our study, the short rise is prominent in Tone 2, Tone 3, and sandhi Tone 4 in both monosyllables and disyllables. However, none of the previous studies have touched on this area. Given that there is no such phenomenon in Standard Mandarin, it is likely that this is a feature of the Heze Dialect. It is also possible that the relatively lower fluctuation in pitch value shown in our study can be explained by this difference in method from previous studies.

In terms of the disyllabic tokens, the pitch of the second syllable tends to match the original monosyllabic tone. Thus, the directionality of the Tone 4 sandhi presented here appears to be from right to left. However, further work would need to be done to determine the directionality of sandhi in the Heze Dialect as a whole. In Tone 4+Tone 2, the shape of the sandhi Tone 4 is almost the same as the monosyllabic tone, which indicates that tone sandhi may not be significant in the Tone 4+Tone 2 pattern. However, there is a small difference in this context in that there is a short rise at the end of the Tone 4. This is probably due to the similarity of Tone 4 and Tone 2, since both have a falling pattern, and the first syllable needs to rise at the end to ensure the second syllable can have the proper fall in its tone.

Finally, there was a tendency for the tone normalization to assign lower values to the productions of the male participants than the female participants. It is not clear why this should be occurring, but the normalization method should be reviewed to determine whether it has a bias by giving male productions lower values and female productions higher values.

7. Conclusion

In this study, we designed two tasks to explore the four base tones and Tone 4 sandhi in Heze Chinese. Our results largely conformed to previous studies, with only minor differences.

Our study confirmed that tones in the Heze dialect differ from those of Standard Mandarin. While Standard Mandarin is classified as Tone 1: [55], Tone 2: [35], Tone 3: [214], and Tone 4: [51], our study found that the tones in the Heze dialect were Tone 1:

[323], Tone 2: [342], Tone 3: [33], and Tone 4: [423]. Our findings for Tone 1 and Tone 4 were similar to previous research by Jiang (2016) and Yang (2015) by being falling-rising contour tones, but with slight differences in the exact numerical description of each. Our findings agreed with past research that Tone 4 is slightly higher than Tone 1. Our results also agreed with the previous research that Tone 3 is flat, but we found its value to be a bit lower at [33]. While Tone 2 was considered falling in previous research, our findings suggest it is a rising-falling contour.

To achieve more meaningful and wide-reaching results, more participants need to be recruited. With these participants, it would be helpful to consider additional factors, such as syllable structure when designing stimuli. In addition, this study leads to some additional future questions. First, our study only focused on tone sandhi in disyllabic words, so what would the tones be like in trisyllabic words or four-syllable idioms? Second, how is sandhi affected by morphosyntactic environment? Finally, the possibility of sandhi with the other tones in the Heze dialect should be explored.

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Appendix

Table 8

Characters and glosses for disyllabic stimuli

T4+T1	Words	Pinyin	Gloss	T4+T2	Words	Pinyin	Gloss
A	地区	dì.qū	'area'	A	地球	dì.qiú	'earth'
B	四川	sì.chuān	'Sichuan'	B	内容	nèi.róng	'content'
C	信封	xìn.fēng	'envelope'	C	造船	zào.chuán	'shipbuilding'
D	受灾	shòu.zāi	'disaster affected'	D	肺炎	fèi.yán	'pneumonia'
T4+T3	**Words**	**Pinyin**	**Gloss**	**T4+T4**	**Words**	**Pinyin**	**Gloss**
A	汉语	hàn.yǔ	'Chinese'	A	运动	yùn.dòng	'sports'
B	电影	diàn.yǐng	'movie'	B	电话	diàn.huà	'phone'
C	画展	huà.zhǎn	'art exhibition'	C	静电	jìng.diàn	'static electricity'
D	臭氧	chòu.yǎng	'ozone'	D	社论	shè.lùn	'editorial'