Linguistic Research 33(1), 21-38
DOI: 10.17250/khisli.33.1.201603.002

The phonetic realization of devoiced vowels in Mandarin Chinese*

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Han, Jeong-Im and Sujin Oh. 2016. The phonetic realization of devoiced vowels in Mandarin Chinese. *Linguistic Research* 33(1), 21-38. This study analyzed the phonetic realizations of devoiced vowels in Mandarin Chinese. First, the target vowels were acoustically examined and classified in three categories: completely devoiced, partially devoiced, and completely voiced. Second, the segmental duration and intensity of the target vowels, and the aspiration/noise duration of the preceding consonants were measured between the devoiced and voiced tokens. Our findings indicate that 1) the vowels of Mandarin Chinese were seldom realized as prototypical devoiced vowels like Japanese or the American Indian languages: the frequency of devoiced vowels was less than 5% regardless of the contexts eliciting vowel devoicing; and 2) there were considerable individual variations across speakers. However, it was also found in the acoustic measurements of the target vowels that the devoiced vowels were realized with shorter duration and lower intensity than the voiced counterparts. As for the duration of the aspiration/noise of the preceding consonants, a voiceless fricative, but not a voiceless affricate or stop, was realized with longer duration when it was immediately preceded by the (completely and partially) devoiced vowel as compared to the completely voiced vowel. The present results demonstrate a cross-linguistic variation in the realization of devoiced vowels. **(Konkuk University)**

Keywords vowel devoicing, phonetic realization, duration, intensity, Mandarin Chinese

1. Introduction

When high vowels or schwa is next to a voiceless consonant, they become voiceless or even deleted. High vowels (and schwa) that are intrinsically short in

* This paper was supported by Konkuk University in 2015. We are grateful to two anonymous reviewers for their thoughtful and constructive comments on the first version of this paper. Our thanks also go to Jae-Woong Yeom and Yun Hui Dang for their help with the Chinese data.

duration and more restricted in size of oral cavity are subjected to be devoiced or deleted in those consonantal environments. This phenomenon of 'vowel devoicing' has been reported in various languages such as Montreal French (Cedergren and Simoneau 1985), Greek (Dauer 1980), Turkish (Jannedy 1995), Korean (Jun and Beckman 1993, 1994), and American Indian languages (Miyashita 2000 for Tohono O'odham; Oberly and Kharlamov 2015 for Southern Ute; Whorf 1934 for Hope). However, it has been studied more extensively in Tokyo Japanese where the high vowel /i/ or /u/ is deleted or devoiced between voiceless obstruents (e.g., [k**i**ta] 'north', [k**u**sa] 'grass') (Kondo 2005; Kubozono 1999; Ogasawara 2014). Vowel devoicing in Tokyo Japanese has been described as a phonological process in the literature where it is represented as a change of the feature [+voice] or segmental deletion (Bloch 1950). However, vowel devoicing is shown to be influenced by various linguistic factors including position in an utterance, syllable structure, speech style, speaking rate, and/or dialect (Kondo 2005). For example, Jun, Beckman, Niimi, and Tiede (1997) showed that the vowel devoicing in Korean shows variability in the degree of devoicing in both acoustic and EMG signals, and in the patterns of glottal closing and opening across different tokens. Based on the results, Jun et al. (1997) argued that vowel devoicing is not a phonological process, but a kind of gradient phonetic effect resulting from subtle adjustments to the timing of invariant gestural specifications.

Vowel devoicing also occurs in Mandarin Chinese. According to the phonological descriptions (Duanmu 2000; Lin 2007; Zee 1990, 2003; Jo 1994; Eo 1995), high vowels such as /i, u, y/ become voiceless or even deleted when next to a voiceless fricative/affricate or a voiceless aspirated stop. It is optionally processed, but when it applies, it occurs most commonly in an unstressed neutral-toned syllable, and in fast speech. The realization of vowel devoicing has been described to be dialect-specific and in some southern dialects, vowels are rarely devoiced without any tone change even in the target syllable (Mo, J. 2011). Specifically, vowels are described to be devoiced in the following four environments in Mandarin Chinese.

(1) Vowel devoicing in the syllable with a neutral tone

a. high vowel → [-voice] / [-voice] fricative/affricate _____

$\text{li}_{53}\ \text{tɕ}^{\text{h}}\text{i}_{1}$ → $\text{li}_{53}\ \text{tɕ}^{\text{h}}\text{i̥}_{1}$ 'physical strength'

b. high vowel → [-voice] / [-voice, +aspirated] stop _____ wən$_{53}$ t^{h}i$_{1}$ → wən$_{53}$ t^{h}i̥$_{1}$ 'question'

c. syllabic consonant → [-voice] / [-voice] fricative/affricate _____

san$_{55}$ ts^{h}ɹ̩$_{2}$ → san$_{55}$ ts^{h}ɹ̩$_{2}$ 'three times'

d. high vowel → [-voice] / [+aspirated] consonant _____

tɕ^{h}i$_{21}$ sɹ̩$_{55}$ → tɕ^{h}i̥$_{21}$ sɹ̩$_{55}$ 'cheese'

(Lin 2007: 164-165)

As in the examples of (1), high vowels are devoiced after a voiceless fricative/affricate (1a) or a voiceless aspirated stop (1b). In addition to the high vowels, the syllabic consonant, /ɹ̩/, triggers vowel devoicing after a voiceless fricative/affricate (1c). These three examples are the case where vowel devoicing occurs in the final syllable, because the neutral tone usually occurs in this position. However, vowel devoicing also occurs in a non-final syllable as in (1d), where high vowels are devoiced after aspirated stops in the low-toned syllable.

Despite these phonological descriptions, limited acoustic data are available for the vowel devoicing in Mandarin Chinese and thus it is not clear how such vowels are actually realized at the phonetic level. The purpose of the present study is to examine the phonetic realizations of devoiced vowels in Mandarin Chinese. We describe the phonetic forms of devoiced vowels based on the data from six native speakers of Mandarin Chinese. Specifically the frequency of devoiced vowels in the production was calculated, and then temporal and spectral measurements of the target vowel were done.

2. Method

2.1 Participants

Six male native speakers of Mandarin Chinese participated in the experiment. Their ages ranged from 19 to 27, with an average age of 22.75. The speakers came from various places of China: Two of them were from Harbin, and each of the remaining speakers was from Shenyang, Shaanxi, Shanghai, and Chongqing. These areas, except Shanghai, have been classified as those for Mandarin dialect, and it is also known that vowel devoicing is common in Shanghai dialect (Zee 2003).

2.2 Stimuli

Based on the phonological descriptions by Lin (2007) as shown in (1), four different sets of stimuli were constructed according to the phonological environments that trigger the vowel devoicing process.

Table 1. Examples of the test words

target/environment	stimulus			
	voiced V	devoiced V	Pinyin	gloss
high V vless fric./affr. __	東西 tuŋ55 ɕi2	tuŋ55 ɕi̥2	dōngxi	thing
high V vless, asp. stop --	俏皮 tɕʰiɑu51 pʰi1	tɕʰiɑu51 pʰi̥1	qiàopi	good-looking
syllabic C vless fric./affr. __	柿子 ʂɹ̩53 tsɹ̩1	ʂɹ̩53 tsɹ̩̊1	shizi	persimmon
high V (non-final) vless, asp. stop __	匹敵 pʰi21 ti35	pʰi̥21 ti35	pǐdí	well matched

The phonological environments triggering vowel devoicing are divided into four types: a) final high vowels (/i, u/) after voiceless fricatives/affricates; b) final high vowels (/i, u/) after voiceless aspirated stops; c) a syllabic consonant, /ɹ̩/, after voiceless fricatives/affricates; and d) non-final high vowels (/i, u/) after voiceless aspirated stops. The first three types contain the target vowels in the neutral-toned syllable, whereas in the last type of environment, devoiced vowels occur in the low-toned syllable.[1] Given that it was not easy to collect equal numbers of tokens for four types of phonological environments and three target high vowels, the exact numbers of the tokens were not identical across contexts. For the same reason, the vowel /y/ was not included in this experiment. Sixty-seven test words were selected in total (20 tokens for a type, 6 for b type, 19 for c type, and 22 for d type) and thus 402 tokens (6 participants x 67 words) were used for analysis. The complete list of the test words is presented in Appendix A.

1 The two tokens in the d) context, /tʰu21 ti51/ and /kʰun51 nan1/, have different tone specifications from those of the other tokens (See Appendix A). The reason for the inclusion of these two tokens is that their tone specification shows variation in the literature. For example, Duanmu (2000) argues that the first syllable of /kʰun51 nan1/ has a low tone and thus it undergoes vowel devoicing (Duanmu 2000: 257). As a matter of fact, the first vowel of /tʰu21 ti51/ was shown to be partially devoiced in the first speaker of our study.

2.3 Procedure

Each participant was recorded in a sound-proof booth using a Tascam HD-P2 solid-state recorder and a Shure KSM 44 microphone. Before recording, the participants completed a questionnaire on their biographical and language background informations. The test words were presented in a frame sentence (e.g., 我說了___三次 'I said ___ three times'). Each participant was instructed to read randomized sentences at a regular rate first, and then at a much faster rate to elicit the speech tokens with devoiced tokens. Only the sentences read at fast speech rate was used for analysis and the time to complete the recording was approximately 20 minutes. The recorded material was sampled at 44,1kHz with 16-bit quantization.

2.4 Measurements and analyses

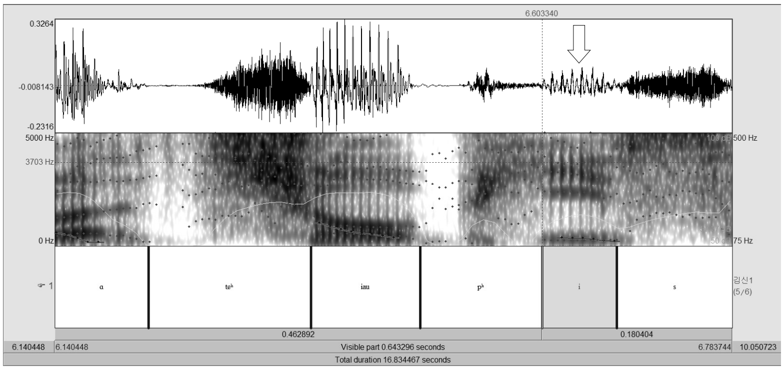
In order to investigate the frequency of devoiced vs. voiced vowels in production, each token was analyzed acoustically by two authors based on its waveform and spectrogram. First, realizations of the target vowels were categorized into three types: 1) completely voiced, 2) partially devoiced—a small number of periodic waves with very low amplitude were observed, but the acoustic quality of the vowel was different from the completely voiced vowel, and 3) completely devoiced/deleted—neither voice bar nor periodic waves were observed, but there were faint formants visible enough to trace the vowel for 'completely devoiced'; no acoustic property of the vowel but only frication was observed after the release of closure for 'deleted.' The criteria for this categorization are similar to the ones by Jun and Beckman (1994) for Korean and Ogasawara (2014) for Japanese. Subsequently three acoustic measurements were done: 1) segmental duration of the target vowel, 2) intensity of the target vowel, and 3) segmental duration of the release (aspiration or noise) of the preceding consonant. The analysis of the preceding consonant was based on the results of the previous studies reporting consistent effects of voicing of the target vowel on the acoustic properties of the preceding consonants. Specifically, the duration of release for stops and affricates, and the duration of noise for fricatives were shown to be affected by voicing of the immediately following vowel (Mo, Y. 2007; Oberly and Kharlamov 2015). Segmental duration was measured in milliseconds. As for vowel duration, the onset and offset of the vowel were determined based on the presence of formant structure in the spectrogram and the presence of periodic cycles in the waveform. The duration of the fricative was measured from the onset of the aperiodic frication to the offset of the frication of the consonant, whereas the release duration of the aspirated stop and the affricate was measured from the spike (oral release) to the presence of formant structure and also the periodic cycles of the immediately following vowel (Oberly and Kharlamov 2015). The vowel intensity was measured in decibel (dB) using high-pass-filtered data and a window set at 70% of the segment duration (Oberly and Kharlamov 2015).

3. Results

3.1 Phonetic realization of devoiced vowels in Mandarin Chinese

Sample waveforms and spectrograms for completely voiced, partially voiced, and completely devoiced tokens are presented in Figure 1.

1)



2)

3)

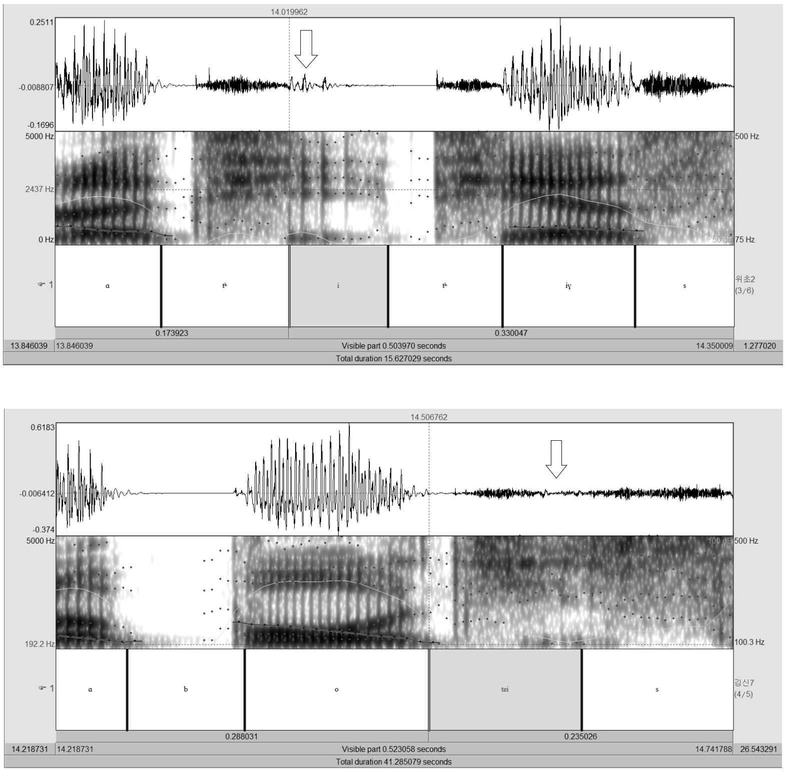
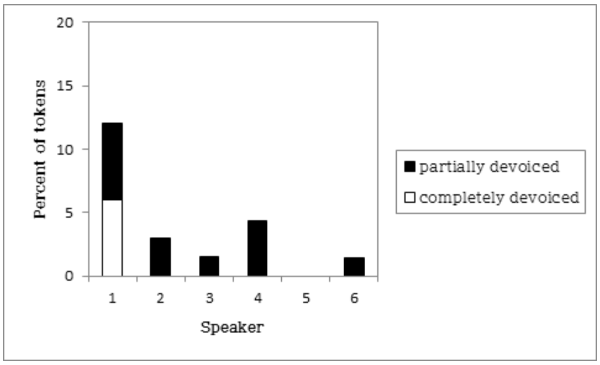


Figure 1. Sample waveforms and spectrograms of 1) /tɕ^{h}iɑu$_{51}$ p^{h}**i**$_{1}$/ as a completely voiced token, 2) /t^{h}**i**$_{21}$ t^{h}iɤ$_{55}$/ as a partially devoiced token, and 3) /bo$_{51}$ tɕ**i**$_{1}$/ as a completely devoiced token

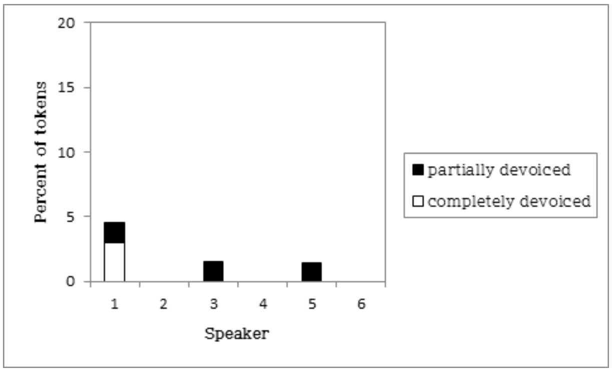
In the example of /tɕ^{h}iɑu$_{51}$ p^{h}**i**$_{1}$/ (1), the second vowel was considered as completely voiced based on the fact that a large number of periodic waves with high amplitude, and a formant structure are observed. On the other hand, the second vowel of /bo$_{51}$ tɕ**i**$_{1}$/ (3) do not show any acoustic property of the vowel after the frication noise of the preceding consonant, which was classified as completely devoiced token. In the first vowel of the example /t^{h}**i**$_{21}$ t^{h}iɤ$_{55}$/ (2), one or two periodic waves are observed but there are no clear formants visible enough to characterize the vowel. This token was classified as partially devoiced.

Producing incorrect words, mispronunciations, and no responses were regarded as errors which were not included for analysis. There were 5 errors out of 402 tokens (0.012%). Figure 2 shows the mean percentage of completely devoiced and partially devoiced vowels in four different contexts over the productions by all six speakers.

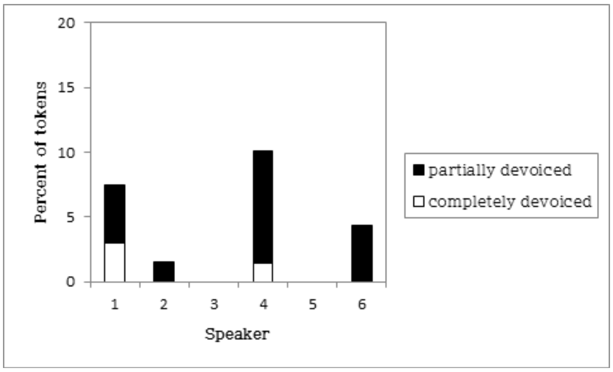
1)



2)



3)



4)

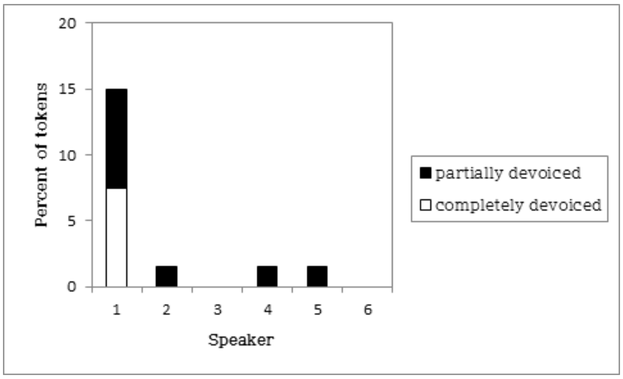


Figure 2. Percentage of tokens (%) in which the vowel was completely or partially devoiced in the context of 1) final high vowels after voiceless fricatives/affricates; 2) final high vowels after voiceless aspirated stops; 3) a syllabic consonant after voiceless fricatives/affricates; and 4) non-final high vowels after aspirated stops (top to bottom) for each speaker.

Figure 2 demonstrates that relatively small numbers of tokens were devoiced in Mandarin Chinese regardless of specific contexts. The mean percentage of devoiced tokens averaged all six speakers was 3.7% for the first context (final high vowels after voiceless fricatives/affricates), 1.2% for the second context (final high vowels after voiceless aspirated stops), 3.9% for the third context (a syllabic consonant after voiceless fricatives/affricates), and 3.2% for the fourth context (non-final high vowels after aspirated stops). Thus less than 5% of tokens were shown to be devoiced in this language.

Another major result evident in Figure 2 is that there were considerable individual variations across speakers in the production of the target vowels. The speaker #1 produced relatively large numbers of tokens as devoiced regardless of the contexts, whereas other speakers seldom produced the target vowels as devoiced. Furthermore, the devoiced tokens from the speakers except the speaker #1 were mostly limited to the partially devoiced tokens.[2]

2 As both reviewers suggest, it should be acknowledged that the actual realizations of vowel devoicing differ according to the specific dialects of Chinese. One reviewer also points out that Wu Dialect spoken in Shanghai is more likely to become devoiced than any other dialects in Chinese. As briefly described earlier, five out of six participants were from the area where

3.2 Acoustic characteristics of the devoiced vowels

Based on the results of previous studies that devoiced vowels were found to be significantly shorter than voiced ones, and devoiced vowels also showed significantly lower average intensity (e.g., Oberly and Kharlamov 2015), we conducted acoustic analyses of the voiced vs. devoiced vowels in terms of segmental duration and intensity. Table 2 shows the duration and intensity differences between devoiced and voiced vowels.

Table 2. Mean duration (ms) and intensity (dB) of the target vowels /i/, /u/, and /ɹ̩/

target vowel	duration		intensity	
	devoiced	voiced	devoiced	voiced
/i/	52.9	87.5	40.9	64.4
/u/	62.8	92.3	47.2	64.9
/ɹ̩/	38.6	85.1	38.9	63.4

As the acoustic characteristics of the adjacent consonants were various, the measurements were based on the mean values of the target vowels across the various preceding consonants (stops vs. fricatives vs. affricates). Analyses of Variance (ANOVA) showed that for all three vowel types, the segmental durations were significantly different between devoiced and voiced vowels [$F(1,122) = 33.6$, p=.000 for /i/; $F(1,170) = 39.67$, p=.000 for /u/; $F(1,111) = 54.8$, p=.000 for syllabic consonant]. The devoiced vowels were significantly shorter than the corresponding voiced vowels. Similarly, there was a main effect of presence of voicing on the intensity of the target vowel: the intensity of devoiced vowels was significantly lower than that of the corresponding voiced counterparts [$F(1,122) = 90.1$, p=.000 for /i/; $F(1,170) = 74.5$, p=.000 for /u/; $F(1,111) = 71.6$, p=.000 for /ɹ̩/]. This result demonstrates that the devoiced vowels are less loud than their voiced counterparts.

Mandarin Dialect was spoken, and the other participant was from Shanghai, even though all participants spoke in Mandarin Chinese at the time of experiment. The results of this study, however, demonstrate that the participant from Shanghai (#2 in Figure 2) did not produce relatively large numbers of tokens as devoiced, and that the participants who came from the same regional dialect area (Mandarin) showed a large difference in the degree of vowel devoicing (#1 vs. #3, #4, #5, and #6 in Figure 2). Thus we failed to see a clear effect of dialects in the realization of vowel devoicing in Chinese. Based on these results, it can be argued that there were considerable individual variations across speakers rather than dialectal variations.

Table 3 shows the duration differences of the preceding consonant between devoiced and voiced vowels.

Table 3. Mean durations (ms) of aspiration/noise of the preceding consonants

preceding consonant	duration	
	devoiced	voiced
fricatives	94.6	81.6
affricates	76.1	73.3
stops	85.3	80.2

Analysis of variance (ANOVA) was separately carried out to the three types of preceding consonants. The fricatives demonstrated a significant effect of vowel devoicing [$F(1,106) = 5.40$, $p<.05$]; the fricatives preceding the devoiced vowels were significantly longer than those preceding the corresponding voiced vowels. However, neither affricates nor stops showed significant duration differences between devoiced and voiced vowels [$F(1,173) = .883$, $p>.05$ for stops; $F(1,123) = 0.91$, $p>.05$ for affricates].

4. General discussion

Mandarin Chinese has been known for the presence of devoiced vowels in the phonological literature. However, very little is known about how they are actually realized at the phonetic level. The present study examined the phonetic realizations of devoiced vowels from six male speakers of Mandarin Chinese. The present results reported above show that the pattern of phonetic realization of devoiced vowels in Mandarin Chinese looks very similar to that of the languages which are attested to show vowel devoicing. The devoiced vowels showed variability and gradation in devoicing such that they were realized as completely devoiced, partially devoiced, and completely voiced tokens, which has been attested in many other languages (e.g., Montreal French in Cedergren and Simoneau 1985; Korean in Jun and Beckman 1993; Japanese in Ogasawara 2012; Southern Ute in Oberly and Kharlamov 2015).

However, despite varied realizations of devoiced vowels in this language, the vowels of Mandarin Chinese are seldom realized as prototypical devoiced vowels.

The frequency of devoiced vowels (including completely and partially devoiced ones) is much less than that observed in other languages such as Japanese, Korean, and the American Indian languages. The actual frequency of vowel devoicing was less than 5% of the tokens in Mandarin Chinese. Given that the frequency of devoiced vowels was up to 41.9% in Japanese (Ogasawara 2014) and 22.4% in Korean (Mo, Y. 2007), it can be said that vowel devoicing is not frequent in Mandarin Chinese. There might be several possibilities to this cross-linguistic difference. As described earlier, the vowel devoicing process in Mandarin Chinese is an optional process, whereas it is obligatorily processed in Japanese, for example. When the high vowels /i/ and /u/ are placed between voiceless obstruents or a voiceless obstruent and a pause, vowel devoicing "occurs nearly 100% of the time, at least in the Tokyo dialect of Japanese" (Ogasawara 2014: 8). Thus, even though many languages are described to show vowel devoicing in the phonological literature, the actual realizations of the devoiced vowels might be different cross-linguistically.

Another likely explanation for the low frequency of devoiced vowel tokens in Mandarin Chinese is that we might not elicit the spontaneous speech where vowel devoicing is frequently occurring. Even though we controlled the speech rate and analyzed the vowel productions at a fast rate of speech only, the participants could pronounce the test words rather clearly in a laboratory setting. Jun and Beckman (1994), for example, used the corpus of dialogues that contained two pairs of question and answer sentences and the target word was realized without any focus in the answer sentence. However, this explanation might not be tenable in that some previous studies used a similar method to that of our study: participants read the frame sentences with the target words at various rates (Jannedy 1995 for Turkish; Mo, Y. 2007 for Korean).

The observed reduction of target vowels is consistent with the cross-linguistic findings about the effect of vowel devoicing on the duration and intensity of the vowel. Like other languages, the vowels which were realized as devoiced were significantly shorter than the corresponding voiced vowels; and the devoiced vowels were also significantly less loud than the voiced vowels. Another observation related to devoicing is that albeit limited to the fricatives, Mandarin Chinese also showed similar effect of duration of the preceding consonant, with the segment becoming longer when the devoiced vowel is not pronounced as a full segment (vowel). Davidson (2006) and Mo, Y. (2007) already showed that syllables with devoiced sounds have the same or even longer durations than identical syllables with voiced vowels. This lengthening of the preceding consonants can enhance the perceptibility of the target vowels even with very little acoustic information of the vowels due to reduction. The combined results of duration and intensity differences indicate that even without the presence of voicelessness in acoustic outputs, the acoustic signal still contains cues which can distinguish devoiced from completely voiced vowels.

The lack of the effect of voicing on the duration of the preceding stop and affricate in our study is not in line with the general results of previous studies (Jun and Beckman 1994; Mo, Y. 2007; Oberly and Kharlamov 2015). For example, Oberly and Kharlamov (2015) demonstrated significant lengthening of releases (i.e., aspirations for stops) of the obstruents when they were followed by devoiced vowels as compared to the completely voiced ones. Based on this result, Oberly and Kharlamov argued that the acoustic properties of releases reveal the presence of a syllabic element at the phonological level. Based on the data provided in our study, it is not clear at this point whether the null effect of the preceding stop/affricate in Mandarin Chinese is language-specific. More systematic study is required to clarify the effect of vowel devoicing on the preceding consonant in Mandarin Chinese.[3]

In conclusion, on the basis of temporal and spectral observations, we show that the high vowels of Mandarin Chinese are rarely realized as prototypical devoiced vowels like Japanese. However, we also show that the devoiced vowels are realized with shorter duration and lower intensity than the voiced counterparts. The effect of the preceding consonants is shown to be limited to fricatives. The results of this study suggest cross-linguistic variations in the acoustic realization of devoiced vowels.

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3 One reviewer presents an alternative view that lack of the aspiration/noise duration effect for stops/affricates is attributed to relatively short duration of the neutral-toned syllables. To prove this view, he/she also suggests us to compare the duration of aspiration/noise of the stops/affricates between the final and non-final positions. In this study, only stops occurred in both final and non-final positions, as shown in the second and the fourth environments in (1) and Table 1. However, the conducted ANOVA revealed no significant interaction between voicing (voiced vs. devoiced) and environment (final vs. non-final) [$F(1, 171)=1.532$, $p>.05$]. This result suggests that there was no significant difference in the aspiration duration effect of stops between the final and non-final positions. More comprehensive study is, however, required to explore this issue. Thanks to the reviewer for bringing up this point.

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Appendix A

Test words

1) [i, u] / voiceless fricative/affricate ____

word	IPA	Pinyin	meaning
東西	tuŋ$_{55}$ ɕi$_{2}$	dōngxi	thing
力气	li$_{53}$ tɕ^{h}i$_{1}$	lìqi	physical strength
机器	ji$_{55}$ tɕ^{h}i$_{51}$	jīqì	machine
編輯	bian$_{55}$ tɕi$_{2}$	biānji	edit
天气	t^{h}ian$_{55}$ tɕ^{h}i$_{51}$	tiānqì	weather
親戚	tɕ^{h}in$_{55}$ tɕ^{h}i$_{2}$	qīnqi	relative
神气	ʂən$_{35}$ tɕ^{h}i$_{2}$	shénqì	vigorous
俗气	su$_{35}$ tɕ^{h}i$_{2}$	súqi	vulgar
簸箕	bo$_{51}$ tɕi$_{1}$	bòji	dustpan
算數	swan$_{53}$ ʂu$_{1}$	suànshù	arithmetic
大夫	tai$_{53}$ fu$_{1}$	dàifu	doctor
窗戶	tʂuɑŋ$_{55}$ xu$_{2}$	chuānghu	window
歲數	suei$_{51}$ ʂu$_{1}$	suìshù	age
舒服	ʂu$_{55}$ fu$_{2}$	shūfu	be well
熱乎	ʐɣ$_{51}$ xu$_{1}$	rèhu	hot
對付	tuei$_{51}$ fu$_{1}$	duìfu	deal with
含糊	xan$_{35}$ xu$_{2}$	hánhu	ambiguous
長處	tʂ^{h}ɑŋ$_{35}$ tʂ^{h}u$_{1}$	chángchu	merits
財主	ts^{h}ai$_{35}$ tʂu$_{2}$	cáizhǔ	rich man
錯處	ts^{h}uo$_{51}$ tʂ^{h}u$_{1}$	cuòchu	fault

2) [i, u] / voiceless aspirated stop ____

word	IPA	Pinyin	meaning
俏皮	tɕ^{h}iɑu$_{51}$ p^{h}i$_{1}$	qiàopi	good-looking
問題	wən$_{53}$ t^{h}i$_{1}$	wènti	question
挑剔	t^{h}iɑu$_{55}$ t^{h}i$_{2}$	tiāoti	capricious
辛苦	ɕin$_{55}$ k^{h}u$_{2}$	xīnkǔ	laborious
糊涂	xu$_{35}$ t^{h}u$_{2}$	hútu	muddled
挖苦	ua$_{55}$ k^{h}u$_{2}$	wāku	whip

3) [ɹ̩] /voiceless fricative/affricate ____

word	IPA	Pinyin	meaning
三次	san$_{55}$ ts^{h}ɹ̩$_{2}$	sānci	three times
柿子	ʂɹ̩$_{53}$ tsɹ̩$_{1}$	shizi	persimmon
有意思	jou$_{21}$ ji$_{53}$ sɹ̩$_{1}$	yǒuyìsi	interesting
荔枝	li$_{53}$ tʂɹ̩$_{1}$	lìzhī	lichee fruit
但是	tan$_{53}$ ʂɹ̩$_{1}$	dànshì	but
歷史	l^{j}i$_{51}$ ʂɹ̩$_{214}$	lìshì	history
上次	ʂaŋ$_{51}$ ts^{h}ɹ̩$_{1}$	shàngcì	last time
心思	ɕin$_{55}$ sɹ̩$_{2}$	xīnsi	thought
意思	i$_{51}$ sɹ̩$_{2}$	yìsi	thought
踏實	t^{h}a$_{55}$ ʂɹ̩$_{2}$	tāshi	on a firm footing
官司	kuan$_{55}$ sɹ̩$_{2}$	guānsi	lawsuit
干事	kan$_{51}$ ʂɹ̩$_{1}$	gànshi	office-bearer
差事	tʂ^{h}ai$_{55}$ ʂɹ̩$_{1}$	chāishi	assignment
鞭子	pian$_{55}$ tsɹ̩$_{2}$	biānzi	whip
桌子	tʂuo$_{55}$ tsɹ̩$_{1}$	zhuōzi	table
位置	uei$_{51}$ tʂɹ̩$_{1}$	wèizhi	seat
錐子	tʂuei$_{55}$ tsɹ̩$_{2}$	zhuīzi	awl
案子	an$_{51}$ tsɹ̩$_{1}$	ànzi	agenda
胭脂	jan$_{55}$ tʂɹ̩$_{2}$	yānzhi	rouge/blush

4) [i, u] / voiceless aspirated stop ____ consonant

word	IPA	Pinyin	meaning
匹敵	p^{h}i$_{21}$ ti$_{35}$	pǐdí	be well matched
匹夫	p^{h}i$_{21}$ fu$_{55}$	pǐfū	ordinary man
仳离	p^{h}i$_{21}$ li$_{35}$	pǐlí	be separated
普查	p^{h}u$_{21}$ ts^{h}ɑ$_{35}$	pǔchá	general investigation
普通	p^{h}u$_{21}$ t^{h}uŋ$_{55}$	pǔtōng	ordinary
譜牒	p^{h}u$_{21}$ tiɤ$_{35}$	pǔdié	scholarship
朴直	p^{h}u$_{21}$ tʂɹ̩$_{35}$	pǔzhí	honest/straightforward
体貼	t^{h}i$_{21}$ t^{h}iɤ$_{55}$	tǐiē	be considerate to
体型	t^{h}i$_{21}$ ɕiŋ$_{35}$	tǐxíng	body type
体惜	t^{h}i$_{21}$ ɕi$_{55}$	tǐxī	show solicitude for
体裁	t^{h}i$_{21}$ ts^{h}ɑi$_{35}$	tǐcái	modes of expression
土地	t^{h}u$_{21}$ ti$_{51}$	tǔdì	field
徒弟	t^{h}u$_{35}$ t^{j}i$_{51}$	túdì	apprentice
困難	k^{h}un$_{51}$ nan$_{1}$	kùnnan	suffering
土豆	t^{h}u$_{21}$ tou$_{51}$	tǔdòu	potato
土木	t^{h}u$_{21}$ mu$_{51}$	tǔmù	building
土溫	t^{h}u$_{21}$ uən$_{55}$	tǔwēn	land temperature

土邦	t^hu_{21} $paŋ_{55}$	tǔbāng	native state
苦力	k^hu_{21} li_{51}	kǔlì	hard labor
苦笑	k^hu_{21} $ʂiɑu_{51}$	kǔxiào	forced smile
苦寒	k^hu_{21} xan_{35}	kǔhán	bitter cold
苦瓜	k^hu_{21} $kuɑ_{55}$	kǔguā	balsam pear

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Received: 2016. 01. 07.
Revised: 2016. 03. 26.
Accepted: 2016. 03. 26.