Singapore Mandarin Tone Contours and Context Effects

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Abstract

1 Introduction

The aim of this paper is to describe the tones of Singapore Mandarin Chinese (SMC) and its contextual tonal variation. According to the Singapore Census 2000 (Singapore Department of Statistics, 2000), Mandarin is more often spoken in the home than English in Singapore, and among the Chinese languages spoken in Singapore, Mandarin is more often spoken in the home than all other Chinese languages combined. But among people over forty, that last statistic is reversed, and for people over 60, Hokkien (Fujian) is the most common home language. This reflects the fact that most of the Chinese in Singapore immigrated from Min and Yue regions, particularly from Xiamen in Fujian, but over the last 30 years, the government has actively promoted Mandarin (Tan, 2006). Given the sociolinguistic situation, of Mandarin converting from primarily a second language to primarily a first language, over the period of just one generation, the southern Chinese languages likely have had a strong influence on SMC. As published studies of the tones of SMC are wanting in the literature, it would be interesting to document this aspect of SMC, and to compare it with other standard varieties of Mandarin. In particular, this paper explores (a) the tonal contours of Singapore Mandarin, and compares these with the contours of two other standard varieties of Mandarin: Beijing Mandarin and Taiwan Mandarin; (b) the tone sandhi patterns in Singapore Mandarin, and (c) the effects of tonal coarticulation in Singapore Mandarin.

2 Background

This section summarizes the literature regarding Chinese tone sandhi and tonal coarticulation, especially as it relates to Singapore Mandarin Chinese (SMC). We restrict the discussion here to effects of adjacent tones, leaving aside the interaction with accent in the context of intonational phrases (Pan, 2007; Xu, 1999). Beijing Mandarin Chinese (BMC) tonal phonology is very well described, and in recent decades more careful acoustic studies have also been done. But literature on other dialects is much more limited.

Tone sandhi and tonal coarticulation are "tonal variations triggered by tonal context" (Shen, 1992). Shen distinguishes them from each other by three criteria:

- Tone sandhi is an effect of language-specific phonology, whereas tonal coarticulation is an effect of biomechanics.

- Tone coarticulation is said to only involve assimilation, while tone sandhi may involve assimilation or dissimilation

- Tone sandhi makes a categorical change in tone, whereas tonal identity is essentially unchanged in coarticulation.

She then compares the tone changes in BMC of two adjacent third-tones (214+214) to the tone changes when two fourth-tones (51+51) are adjacent. The third-tone change is a commonly-cited example of sandhi, in which the initial third-tone converts to a second-tone (35). Since the third tone change (a) is language-specific (shared by many Mandarin dialects, but with a different phonetic realization in each one) and somewhat lexically and syntactically dependent, (b) it is a dissimilation process, and (c) it converts from one toneme to another, it is considered sandhi. The fourth-tone change, in which the initial fourth tone drops only half-way (53) was cited by Y-R. Chao (1948) as tone sandhi, but acoustic analysis has shown that the effect is more widespread, affecting the fourth tone when followed by any other full tone. This effect is a natural consequence of the vocal folds being unable to instantly change voicing frequency, and effects of tonal crowding like this are found in all languages. Finally, the result of the fourth-tone change is still recognized by speakers as a fourth tone. On the basis of these facts, Shen counts the third-tone change as sandhi and the fourth-tone change as coarticulation.

However, in his discussion of tonal coarticulation, mostly reviewing Shih's (1988) work on TMC, M. Y. Chen (2000) points out that the line between sandhi and coarticulation is not so clear. Each of Shen's criteria sometimes fails, even just within BMC. First, a certain coarticulation effect (35.21 $\rightarrow$ 53.21) is sensitive to syntax, applying across word boundaries but not word internally. Second, there is a slight pitch raising effect on BMC rising and falling tones before the low third tone, i.e. dissimilation. And finally, though speakers cannot hear the difference between the result of third-tone sandhi and an underlying second tone, the one that is underlyingly a third tone has a phonetically lower pitch than the normal second tone, and they are thus not fully merged tonemes. Chen suggests that the difference between sandhi and coarticulation may simply be two ends of a spectrum, distinguished primarily by what linguists can hear. The magnitude of the sandhi pitch alternations does however make them more perceptible to native speakers and thus more likely incorporated into their phonology. In this paper we distinguish sandhi from coarticulation primarily by the (near) categorical change but acknowledge that the distinction is not well-defined.

Both Shih and Shen have done quantitative acoustic studies of Mandarin tonal coarticulation, as have a number of researchers more recently, but the most cited study is Xu (1997). Recordings were made of the token 'mama', with all 16 of the possible combinations of the four tones on the two syllables. The tokens were a mixture of nonsense or bizarre combinations and one token that is a common word ('mother'). The tokens were read by 8 male native speakers of BMC, first read in isolation and then inserted into four carrier sentences, each item repeated six times in succession. They were read in succession rather than randomized because in a pilot recording session, subjects had difficulty reading the randomized list smoothly and without errors. He found a strong carry-over assimilatory effect, extending throughout the rhyme of the following syllable, and extending weakly into the third syllable. This effect was more noticeable in high tones than in low tones. He also found the same weak dissimilatory effect as Shih, but whereas Shih identified it only in rising and falling tones before the low third tone, this data reveals that the high first tone is also raised, and that the effect also occurs (more weakly) before the rising second tone.

The only published phonological studies of SMC include very little description of tone contours, and no discussion of coarticulation effects. Chen (1986) describes the segmental inventory of SMC. He recorded speech samples from 10 informants who spoke Mandarin as a second language and a southern Chinese dialect as a first language, 2 informants each from 5 dialect groups. He compared their segment inventories against BMC pronunciations for the same lexical items, with the pedagogical aim of identifying ways in which Singaporean speakers would need instruction to assimilate their pronunciations to the BMC standard. Using similar methods and aims, he also studied the phonetic realization and phonological awareness of a class of syllables which in BMC bare different tones but which his informants pronounced with tone acoustically similar to BMC falling tone, though not identical to it (C.-Y. Chen, 1983). The syllables of that tone class constitute a distinct class in most of the southern Chinese languages, though it has a different phonetic realization in each dialect. The lack of discussion of the other tones seems to imply that the tonal contours of the other tones are not very different from BMC, and in the professional opinion of the first author (a native of Singapore), the tone class he describes has disappeared now. However, the strong influence of the southern Chinese languages on the segmental inventory and the one-time existence of a non-BMC tone class suggest there may still be differences.

Tonal realization in Taiwan Mandarin Chinese (TMC), the official language of Taiwan, differs from BMC in a number of respects, including having a mid dipping contour (323) for the second tone rather than a high rising contour (35) and marking focus primarily by duration rather than by pitch range expansion (Hsieh, 2005). The literature does not describe any differences between TMC sandhi processes and BMC sandhi, but there is a related difference in that a set of words that undergo destressing and tone loss in BMC (such as "xue.sheng": 35.55 → 35.3) less often do so in TMC (Duanmu, 2000). One hypothesis is that some of these differences are due to the influence of Min on TMC, since 73% of the population speaks Southern Min as a first language. The focus-marking of TMC is like how Taiwanese marks focus (Pan, 2007), but the differences in tone contours are not attributable to Taiwanese Min phonology, since it has a system of seven lexical tones, none of which have dipping contours, and the sandhi is the typical "tone circle" of Min dialects, with tonal realization dependent on position in the tone group, not on particular adjacent tones. Pan also examined tonal coarticulation effects. She observed both carry-over and anticipatory assimilation, each apparent on some tonemes but not on others.

Gu and Lee (2007) studied the effects of tone context and emphatic focus in Cantonese. Cantonese has no tone sandhi, but Gu and Lee do observe both anticipatory and carry-over coarticulation effects and both assimilatory and dissimilatory coarticulation effects. Recordings were of two nonsense syllables, consisting only of vowels and semi-vowels, embedded in a carrier sentence. Each syllable can have any of six tones, and each sentence was said four times by a single speaker. The strongest effect found was one of carry-over assimilation: the onset F_0 of a syllable is higher when the preceding offset is high and low when the preceding offset is low. But there was also a weak carry-over dissimilation: the onset F_0 of a syllable is higher when the penultimate syllable offset is low, and low when the penultimate offset is high. Note that this is the opposite of the third-syllable carry-over assimilation that Xu (1997) found in Beijing Mandarin. The effect was strongest when the penultimate tone was the low falling tone. Anticipatory effects were also found, though weaker. A slight dissimilation was found when a contour tone preceded a particularly low or high tone, and all tone offsets assimilated towards the following tone onset.

The acoustic studies of Chinese tone context effects show some common trends, such as large carry-over assimilation effects (in BMC, TMC, Taiwanese and Cantonese) and smaller anticipatory dissimilation (found in BMC, TMC, and Cantonese, though not Taiwanese), but there are also subtle coarticulation differences that might be language specific, contrary to Shen's criterion. There are no reported major sandhi differences among Standard Mandarin dialects, but there are differences in prototypical tone contours, and possibly other subtle differences. Acoustic studies of SMC have not been published, but since Min and Cantonese act as substrate languages for SMC, it can be hypothesized that SMC tonal phonology may be influenced by them, and thus be different from BMC and TMC. But just as TMC tonal phonology only resembles that of Taiwanese Min in a couple aspects, any differences between SMC and BMC tonal phonology might or might not be attributable to the southern Chinese substrate.

In the light of these issues, the hypotheses that we test in this study are:

A: The tone contours of Singapore Mandarin are different from those of Beijing Mandarin.

B: The tone contours of Singapore Mandarin are different from those of Taiwan Mandarin.

C: L2 speakers of Singapore Mandarin do not extend phonological sandhi rules to nonsense tokens.

D: Singapore Mandarin displays effects of carry-over assimilation.

E: Singapore Mandarin displays effects of anticipatory dissimilation.

3 Experiment 1

3.1 Experimental Method

3.1.1 Speakers and Materials

Four L2 speakers of Singapore Mandarin, two females (TE and RH) and two males (DH and CY), were recruited for the experiments, and the same set of speakers was recorded for both experiments. All the speakers were in their twenties, and at the time of recording, all of them, except CY, were students at UCSD; CY was on a short term attachment program with a laboratory in San Diego. All the speakers were brought up in Singapore, and they each have had at least ten years of Mandarin lessons in school and use some Mandarin in their everyday lives. All four speakers speak Singapore English as a first language, and speak very little of any other languages. All speakers were naive as to the purposes of the experiments.

The first experiment was designed to test hypotheses A and B. In order to compare the tonal contours of Singapore Mandarin with those of Beijing and Taiwan Mandarin, we first needed to establish the canonical forms of each of the four Singapore Mandarin tones produced by the speakers in this study. In addition, since it is the onset or offset value of a tone that is crucially affecting the F_0contour of the adjacent tone (Xu 1994), we need to determine these values for each tone for the purposes of the second experiment. The test words were the same as those used in Xu (1997) and consisted of the syllable /ma/ with the four Mandarin lexical tones:

Table 1: Monosyllable Stimuli List

Pinyin	mā	má	mǎ	mà
Character	妈	麻	马	骂
Gloss	"mother"	"numb"	"horse"	"scold"

The initial nasal consonant /m/ ensures an unbroken F_0 contour throughout each syllable, and the distinct nasal formant structure allows for easier segmentation of the consonant-vowel boundaries. In order to elicit the reading of these words as isolated one word utterances, each of these words was preceded by a question that asks how the word is read, and each question-answer pair was presented on a computer screen in Chinese as a dialogue. Speakers were only required to read the target word. A sample dialogue is shown below:

A: 这个字怎么读?

(How is this character read?)

B: 妈

3.1.2 Procedure and Measurements

The recording took place in a quiet office in the Language Lab in the Department of Linguistics, UCSD. Prior to the recording, the speakers were given a practice session during which the procedure was explained to them; each of the 4 dialogues was shown to them on the computer screen, and they were instructed to read each word as naturally as possibly. The recording was monitored, and during the actual experiment, each slide was repeated four times, and the order of their appearance was randomised. The most natural sounding three repetitions of each word were later selected for analysis by the first author, who is a speaker of Singapore Mandarin.

The material was recorded in Audacity at 44100 Hz sampling frequency, using an Altec Lansing AHS202i headphone microphone. The selected tokens were segmented by hand in Praat, while F_0 and duration measurements were made using Xu's Praat script for F_0 analysis v. 2.6.[1] A sample of an analysed token is shown in Figure 1.

The phonation type of each token was categorised as modal, creaky, or breathy based on the auditorial perception of the authors. A token that was perceived to contain breathy or creaky phonation anywhere in the syllable was classified as breathy or creaky respectively, while tokens that were perceived to have modal voicing throughout the syllable were classified as modal.

[1]http://www.phon.ucl.ac.uk/home/yi/downloads.html

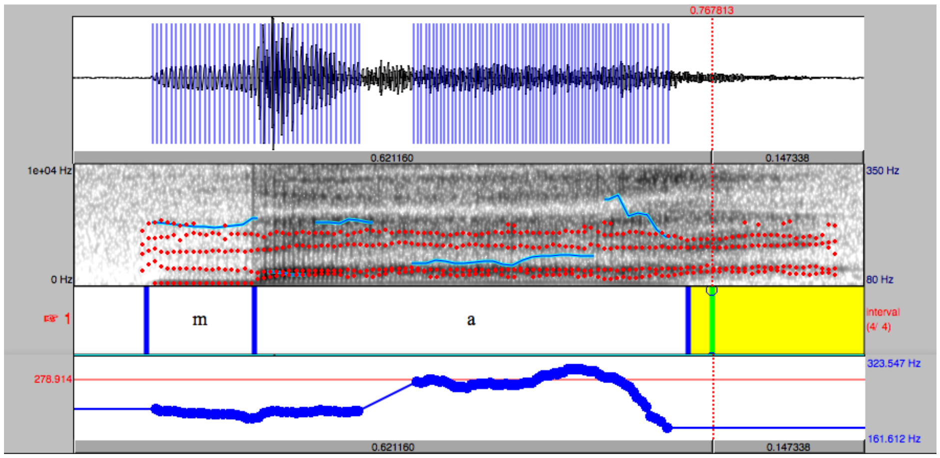


Figure 1: TE *mǎ* waveform and segmentation in Praat, with accompanying pulses and pitch information

3.2 Results

The figure below shows the mean F_0 contours of the syllable /ma/ in the four tones, obtained by averaging over the selected tokens produced by all four speakers (12 utterances for each tone), and plotted as functions of average duration of the vowel. The vertical dotted line indicates the boundary between /m/ and /a/.

Tone 1 starts with a high F_0 value and stays around that level throughout the syllable. Tone 2 starts with a low F_0 value, then falls slightly before rising throughout the remainder of the syllable, and reaches the highest F_0 of all the four tones. Tone 3 starts with a low F_0 value of around the level of the onset of Tone 2 and falls gradually over the duration of the syllable. Tone 4 starts with a high F_0 around the level of the onset of Tone 1, falls sharply to

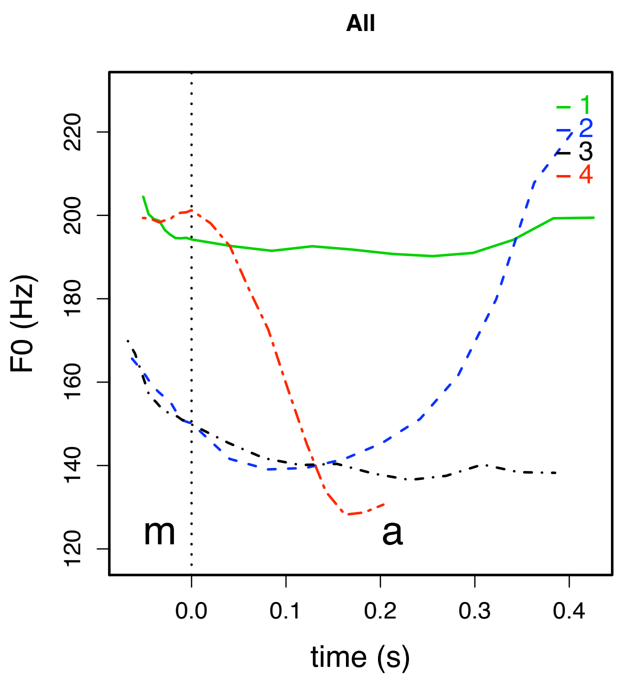


Figure 2: Aggregate mean tone contours for syllable in isolation

reach the lowest F_0 of all the four tones, and shows a small final rise.

In terms of duration, Tone 4 is the shortest tone (260 ms), while Tone 1 is the longest (480 ms), and Tones 2 and 3 are intermediate in duration (470 ms and 460 ms, respectively).

Based on the graph above, we can list the onset and offset values of the four Singapore Mandarin tones in the following table:

Table 2: Tone onset and offset targets

		Offset	
		High	Low
Onset	High	Tone 1	Tone 4
	Low	Tone 2	Tone 3

However, the mean F_0 contours of the four tones seem to show inter-speaker variation. The Figure 3 shows the mean F_0 contours of the syllable in the four tones, obtained by averaging over the selected tokens produced by each speaker (3 utterances for each tone).

In terms of F_0 contour, Tones 2, 3, and 4 show inter-speaker variation. While RH shows a late rise for Tone 2 (starting at about 65% of the vowel duration), the rise occurs much earlier for CY, DH, and TE (50%, 20%, and 30% respectively). For Tone 3, CY and RH show a downward sloping contour with a small rise at the end. The Tone 3 of DH, however, remains fairly constant at a low F_0 value throughout the syllable. In the case of TE, Tone 3 shows an initial falling F_0 contour, after which the F_0 rises and then falls sharply. With regard to Tone 4, DH and TE do not show the final rise

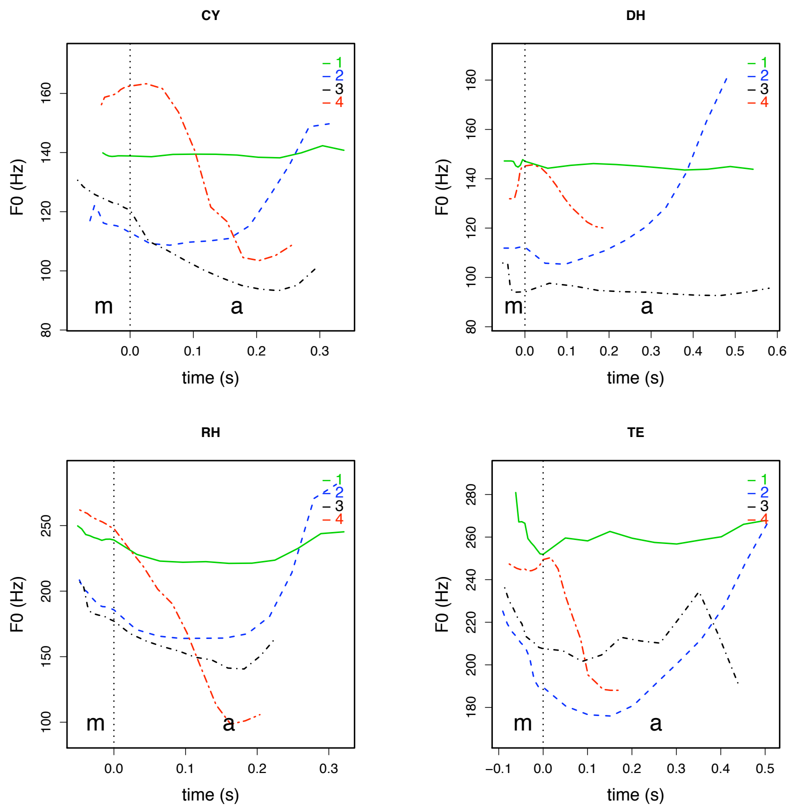


Figure 3: Individual mean tone contours for syllable in isolation

that is displayed by CY and RH.

The Table 3 below shows the perceived phonation type of each token.

Table 3: Phonation type of the syllables in isolation (c=creaky, b=breathy, m=modal)

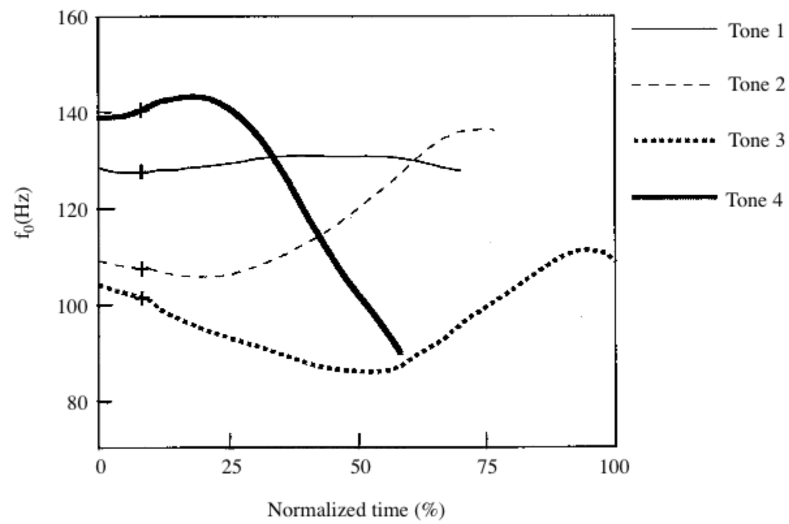
Speaker/ Tone	Tone 1			Tone 2			Tone 3			Tone 4		
RH	m	m	b	m	m	b	c	m	b	c	c	c
TE	b	b	b	b	b	b	b	b	b	m	c	c
DH	m	m	b	m	c	m	c	c	c	c	c	c
CY	b	m	m	b	b	b	b	b	b	m	c	m

As the table shows, there is no phonation type that is exclusive to a particular tone. Even among tokens of the same tone from the same speaker, the phonation type is not always consistent.

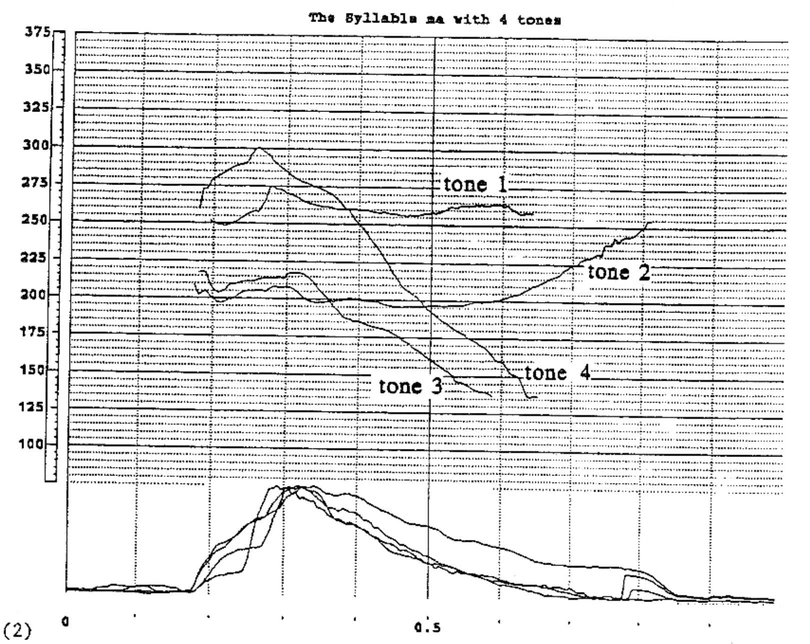
3.3 Discussion

The results from the first experiment show that the onset and offset values of each of the four tones in Singapore Mandarin are similar to those in Beijing Mandarin (Xu, 1997) and Taiwan Mandarin (Shih, 1988). However, the contours and duration of some of the four tones in Singapore Mandarin seem to differ from those of the other two varieties. The tone contours of Beijing Mandarin and Taiwan Mandarin are shown in Figure 4. Unless stated otherwise, we refer to the average of all four speakers when discussing Singapore Mandarin.

In Beijing Mandarin, Tone 3 has the longest duration, Tone 4 has the



a)



b) (2)

Figure 4: Tone contours reported for (a) Beijing Mandarin (Xu, 1997) and (b) Taiwan Mandarin (Shih, 1988)

shortest duration, while Tones 1 and 2 have intermediate durations. On the other hand, Tone 2 is the longest tone in Taiwan Mandarin, while Tone 3 is the shortest, and Tones 1 and 4 have intermediate durations. The tone durations of Singapore Mandarin pattern differently from both of these varieties: while like Beijing Mandarin, Tone 4 is the shortest tone, unlike the other varieties, Tone 1 is the longest tone. Hence, in terms of relative duration, the tones of Singapore Mandarin are neither like those of Beijing Mandarin nor Taiwan Mandarin.

Turning to the F_0 contours, we can see that the F_0 contours of Singapore Mandarin tones exhibit differences from their Beijing and Taiwan counterparts as well. Tone 1 has similar F_0 contours in all three varieties: it starts with a high F_0 value and stays around that level throughout the syllable. While Tone 4 in Beijing and Taiwan Mandarin both show an initial rise before falling, this is not the case in Singapore Mandarin, where Tone 4 simply falls without an initial rise and instead shows a small final rise. Tone 2 of Singapore Mandarin is more similar to that of Beijing Mandarin than Taiwan Mandarin. Like in Beijing Mandarin, it shows an early slight initial fall before rising throughout the remainder of the syllable. In Taiwan Mandarin, Tone 2 "remains level or drops slightly during the first half of the vowel, and rises up to high at the end" (Shih 1988: 83). In the case of Tone 3, however, Singapore Mandarin is more similar to Taiwan Mandarin: it falls and does not show the final rise exhibited in Beijing Mandarin. Thus, when considering the average across speakers, the F_0 contours of the four tones in

Singapore Mandarin are not identical to either of the other two varieties of Mandarin.

The results from experiment 1 therefore suggest that the tonal contours of Singapore Mandarin are different from both Beijing Mandarin and Taiwan Mandarin, and provide support for hypotheses A and B. In addition, the relative durations of the four tones also differ from those of the other varieties.

As noted in the previous section, Tones 2, 3 and 4 show inter-speaker variation in their phonetic realisation. On the assumption that all four speakers share the same phonological representation of the four tones, the data suggest that the onset and offset values of each tone are the important tonal targets in Singapore Mandarin, and that the transition between these targets is unimportant. This is especially clear in the case of Tone 3, where the four speakers show three different slopes between the low onset and low offset, implying that as long as the low onset and offset requirements for a Tone 3 are met, the shape of the actual slope between the two targets does not matter. For Tone 2, RH shows a relatively later and sharper rise than the other speakers, and this again suggests that the actual slope of the transition between the low onset and high offset is inconsequential; what characterises a Tone 2 is the presence of a low onset and a high offset. Similarly, for Tone 4, the final rise is not observed by all speakers, suggesting that the tonal targets are the high onset and the low offset. The small final rise by some speakers can be attributed to the effect of glottalisation at the end of the syllable (Fon). Given that each of the four tones has a different combination of onset and offset values, as shown in table 2, these values are sufficient for the distinction among the four tones, suggesting that the phonological representation of the four tones in Singapore Mandarin is cast solely in terms of these onset and offset values. At this point, this suggestion can only be made tentatively, and further research with more speakers is required in order to determine if this is actually the case.

4 Experiment 2

4.1 Experimental Method

4.1.1 Speakers and Materials

The same set of speakers was recorded for the second experiment, which was also based on Xu (1997), and meant to test hypotheses C through E. The stimuli consisted of the sequences /mama/ with all 16 possible bi-tonal combinations of the four tones. Among them, only the first sequence is a word in Mandarin, meaning 'mother'; the rest are nonsense words.

By having all possible tonal combinations of the two syllables, we can test if Singapore Mandarin exhibits the same sandhi patterns as the other varieties. In particular, since our speakers were L2 speakers, and since most of the stimuli were nonsense words, we wanted to test the hypothesis that L2 speakers do not extend the third tone sandhi rule to nonsense tokens (Hypothesis C).

Table 4: Disyllable Stimuli List

māmā 妈妈	māmá 妈麻	māmǎ 妈马	māmà 妈骂
mámā 麻妈	mámá 麻麻	mámǎ 麻马	mámà 麻骂
mǎmā 马妈	mǎmá 马麻	mǎmǎ 马马	mǎmà 马骂
màmā 骂妈	màmá 骂麻	màmǎ 骂马	màmà 骂骂

The test words were set in different carrier sentences:

- Wǒ qiú <u>māmā</u> liánxi (I begged <u>mama</u> to connect)
- Wǒ qiú <u>māmā</u> liànxí (I begged <u>mama</u> to practice)
- Wǒ jiào <u>māmā</u> liánxi (I told <u>mama</u> to connect)
- Wǒ jiào <u>māmā</u> liànxí (I told <u>mama</u> to practice)

The carrier sentences have the same syntactic structures. There are two different pre-target syllables and two different post-target syllables. In the pre-target pair, emphqiú has a high tonal offset while emphjiào has a low tonal offset. In the post-target pair, emphliàn has a high tonal onset while emphlián has a low tonal onset. As mentioned earlier, it is the onset or offset value of a tone that is crucially affecting the F_0 contour of the adjacent tone (Xu 1994), and by varying the offset and onset values of the pre-target and post-target syllables respectively, we can test the effects of anticipatory and carry-over tonal effects (Hypotheses D and E). Each sentence was presented in Chinese on a computer screen, and there were a total of 64 sentences in the original stimulus set. Unfortunately, in the materials prepared, 8 sentences were duplicated, and the 8 sentences with opposite pre-target and post-target tones were left out.

4.1.2 Procedure and Measurements

The experiment was conducted immediately after the first experiment, in the same room. Prior to the recording, the speakers were given a practice session during which the procedure was explained to them; sample sentences were shown to them on the computer screen, and in order to avoid the situation of the speakers being confused by the tones, they were instructed to read each sentence mentally before repeating it four times in a row as naturally as possibly. Additionally, speakers were told to say the word for 'mother' with the same even stress as the other sequences, instead of the usual trochee associated with that word. The recording was monitored, and during the actual experiment, the order of the slides was randomised. The last three repetitions of each slide were later selected for analysis.

As in the first experiment, the material was recorded in Audacity at 44100 Hz sampling frequency, using an Altec Lansing AHS202i headphone microphone. The selected tokens were segmented by hand in Praat, and the F_0 and time measurements were made with the same script as before. A sample of an analysed token is shown in Figure 5.

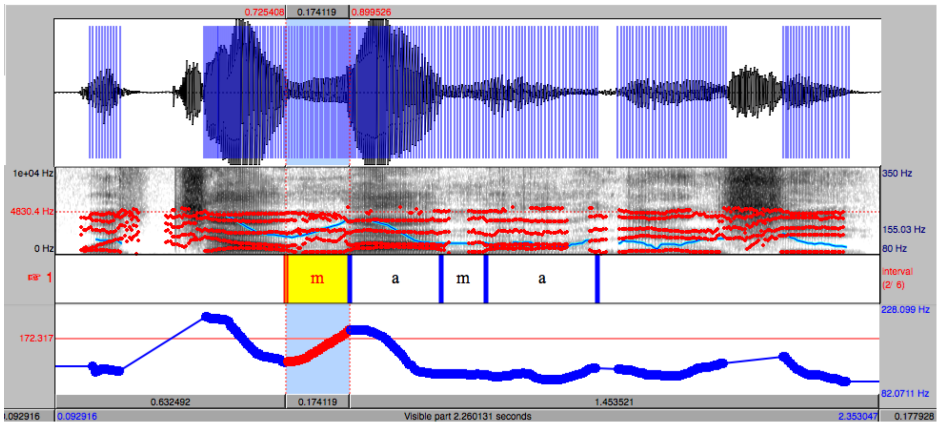


Figure 5: CY jiàomàmǎlián waveform and segmentation in Praat, with accompanying pulses and pitch

In addition to the data points missing due to the left out slides, CY skipped two slides, and DH misread one sentence. To maintain balance in the data, the sentences with pre-target and post-target tones opposite that of missing data points were removed from the data set. For example, CY skipped the slide with emphmámā target, pre-target emphjiào and post-target emphlián, so the CY data for emphmámā with pre-target emphqiú and post-target emphliàn was withheld from all analysis.

Two-factors repeated measures ANOVAs were performed to test Hypotheses D and E. For Hypothesis D, we performed 3 ANOVAs with F_0 at the beginning, middle and end of the second vowel as the dependent variable, and with second syllable target tone and first syllable offset (high or low) as the independent variables. For Hypothesis E, we performed 3 ANOVAs with F_0 at the beginning, middle and end of the first vowel as the dependent variable, and with first syllable target tone and second syllable onset as the independent variables. The F_0 measurements were log transformed to compensate for the higher ranges of higher register voices, and the mean $\log(F_0)$ of each voice was subtracted out to make the measurements more comparable. Because of the third tone sandhi, the data from the emphmǎmǎ target was withheld from the ANOVAs. In addition, after balancing out missing data, no data points remained for DH reading emphmàma3, so emphmàmǎ was also withheld from the ANOVAs, and many tokens in contexts qiú __ liàn and jiào__ qiú were also unavailable, so all data from those two contexts were withheld from the ANOVAs.

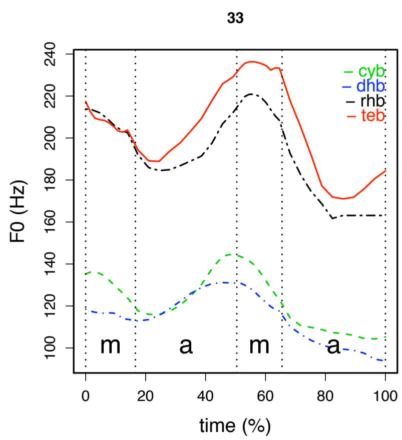
4.2 Tone Sandhi

4.2.1 Results

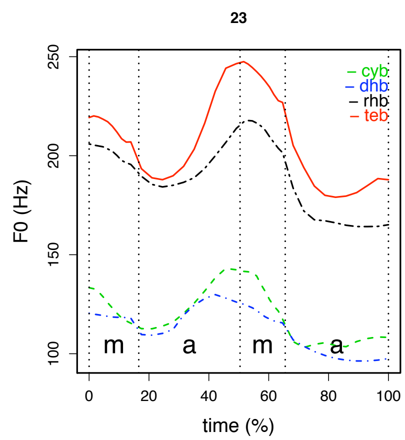
For each of the 16 targets, average F_0 contours for each speaker were plotted together on the same graph against a time scale equalised for all curves. Each of the contours was then compared against the others, and two sandhi effects were noticed.

The first sandhi pattern is the third tone change commonly cited in the literature. Figure 6a below shows the F_0 contour for Tone 3 on both syllables, and Figure 6b shows the F_0 contour for Tones 2 and 3 on the first and second syllable respectively.

The two graphs show similar curves. In Figure 6a, even though both syl-



a)

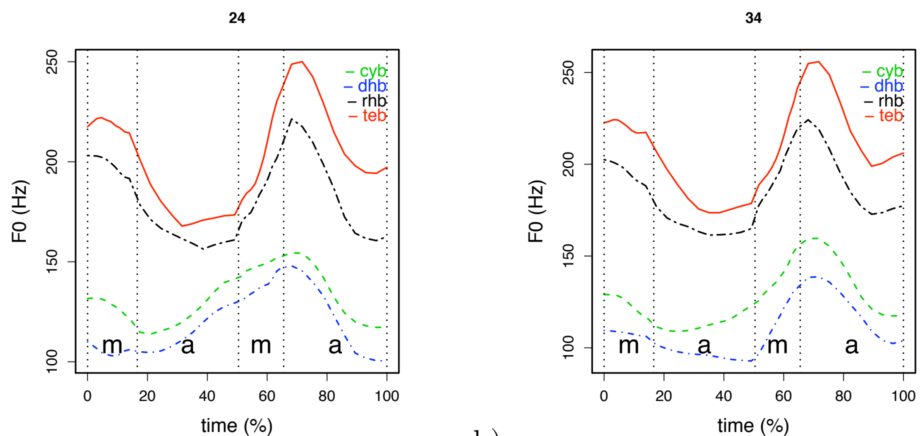


b)

Figure 6: Individual mean F_0 contours for (a) emphmǎmǎ and (b) emphmá-mǎ

lables were represented by characters that were read with Tone 3 in isolation, the first Tone 3 assumes a rising F_0 contour that resembles that of Tone 2, as shown in Figure 6b. That the two graphs are not identical (see Figure 8c below) indicates that tone sandhi did not fully neutralise the differences phonetically, as also seen by Shih (1988) and Xu (1997)

The other sandhi pattern has not been reported in the literature and is exhibited only by some speakers. Figure 7a shows the F_0 contour for Tone 2 on the first syllable and Tone 4 on the second, while Figure 7b shows the F_0 contour for Tone 3 on the first syllable and Tone 4 on the second. As the graphs show, RH and TE have quite similar F_0 contours for both sequences while DH and CY have rather different ones. In Figure 7a, the Tone 2 of RH and TE assume a falling F_0 contour that resembles that of Tone 3, as shown in Figure 7b. For DH and CY however, Tone 2 is a rising tone in Figure 7a.



a) b)

Figure 7: Individual mean F_0 contours for (a) emphmámà and (b) emphmǎmà

4.2.2 Discussion

The Tone 3 sandhi results show that even though the speakers were L2 speakers of Singapore Mandarin, all of them exhibited the third tone change in nonsense words, contrary to hypothesis C. The results strongly show that this particular sandhi rule is very robust in Singapore Mandarin.

The second tone change to Tone 3 when followed by Tone 4 is unexpected as it has not been reported in the literature, and suggests that Singapore Mandarin has its own sandhi rules not found in other varieties. What is particularly interesting is the fact that only the females displayed Tone 2 change while the males did not, suggesting that the presence or absence of this sandhi rule is divided along gender differences. In order to determine the robustness of this sandhi rule in Singapore Mandarin, and if there is indeed a gender difference in the exhibition of this rule, further research with more speakers is required.

4.3 Tonal Coarticulation

4.3.1 Results

The average F_0 contours for all tokens with a particular tone one the second syllable are plotted together in Figure 8. Note that the contour for emphmà-mǎ is abnormally high not because of characteristics of that combination but because we are missing data from DH, who has a low-pitch voice. In the other contours, we can see that there may be a pattern of carry-over assimilation predicted by Hypothesis D, that is, high offsets in the first syllable leading to higher F_0 in the second syllable, but there are exceptions, particular toward the end of the second syllable. The results of the ANOVAs for testing Hypothesis D are displayed in Table AOVD. The effect of pre-tonal offset is highly statistically significant at the beginning of the vowel, but not significant at the middle or end. In fact, by the end of the syllable, the effect direction is opposite what it is at the beginning. In the middle of the syllable, there is a significant interaction between target tone and pre-tonal offset, indicating that some tones are more influenced by the previous offset than other tones are. A Tukey post hoc test showed that the residual differences were primarily between Tone 1 and Tone 3.

The average F_0 contours for all tokens with a particular tone on the first

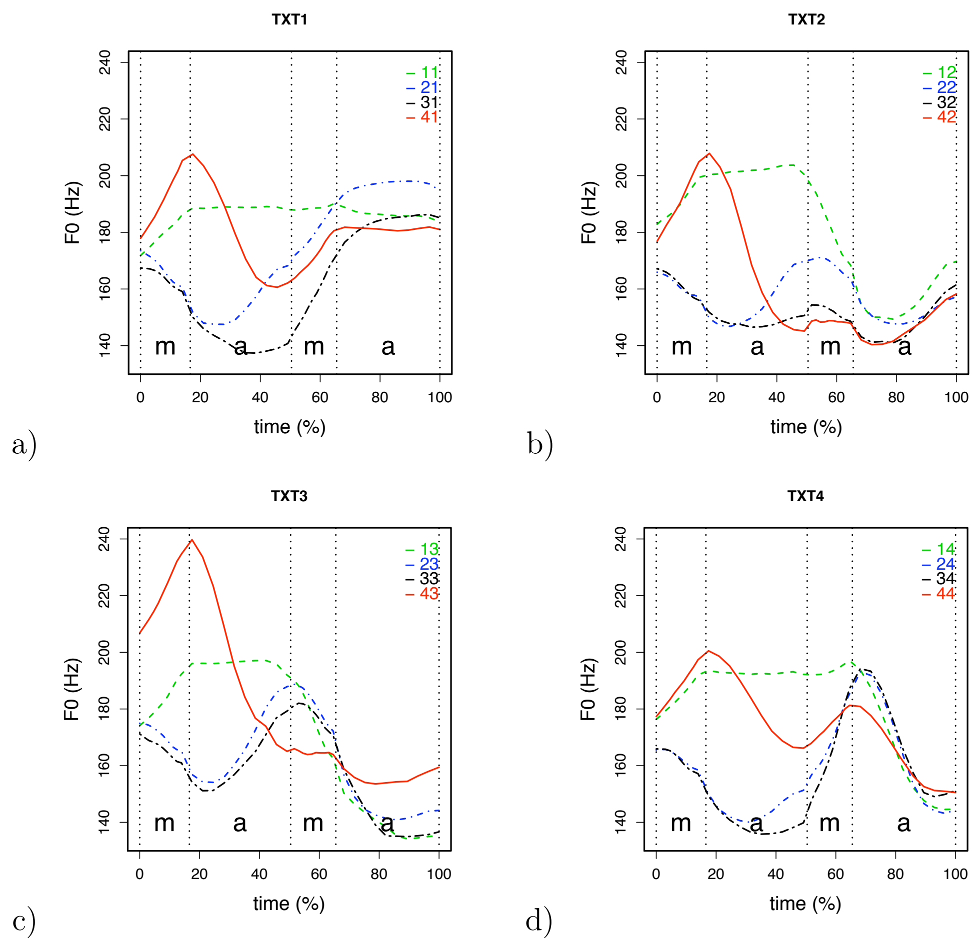


Figure 8: Aggregate mean F_0 contours for stimuli with second syllables having (a) Tone 1 (b) Tone 2 (c) Tone 3 (d) Tone 4

Table 5: ANOVA test of carry-over assimilation

Vowel Initial	Df	F value	Pr(>F)
tone	3	101.7459	< 2.2e-16 ****
pre-tone offset	1	41.6326	9.98e-10 ***
tone x offset	2	1.4728	0.2320
offset effect: -0.97 semi-tones			
Vowel Medial	**Df**	**F value**	**Pr(>F)**
tone	3	170.4700	< 2e-16 ***
pre-tone offset	1	0.7400	0.39082
tone x offset	2	3.0733	0.04872 *
offset effect: -0.14 semi-tones			
Vowel Final	**Df**	**F value**	**Pr(>F)**
tone	3	88.5878	<2e-16 ***
pre-tone offset	1	0.6176	0.4330
tone x offset	2	2.1957	0.1143
offset effect: 0.18 semi-tones			
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1			

syllable are plotted together in Figure 9. We can see that there does appear

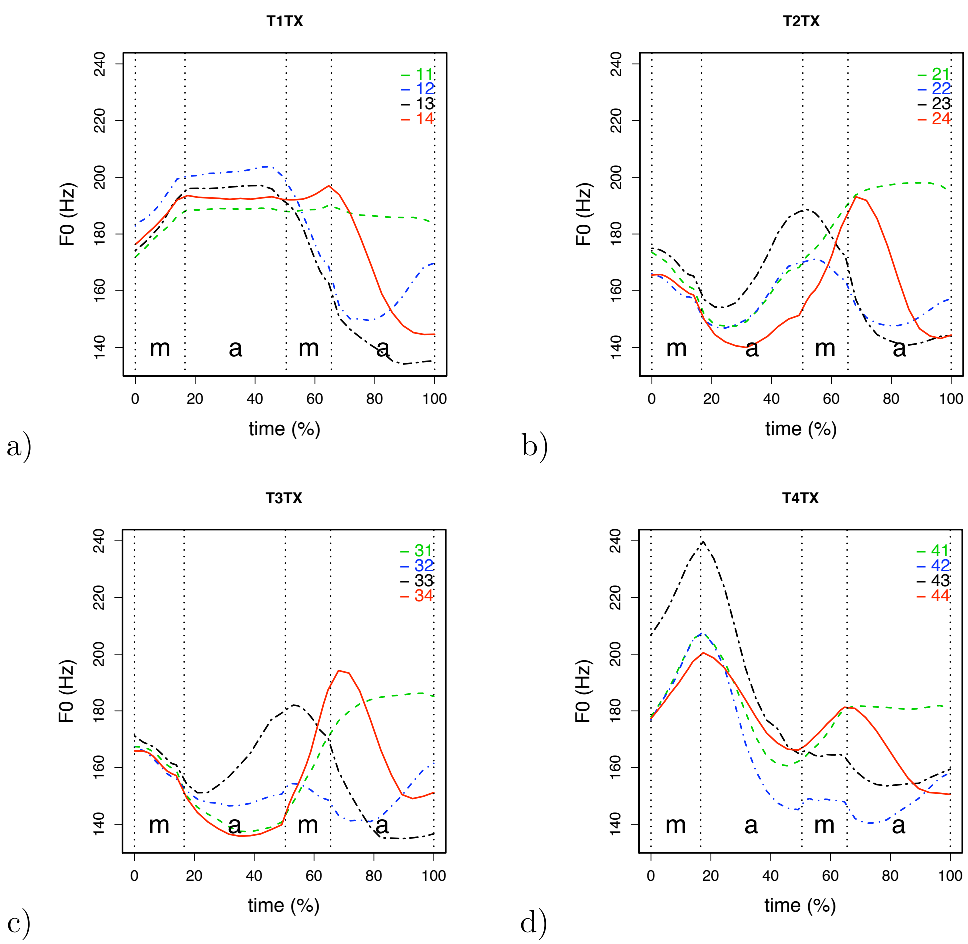


Figure 9: Aggregate mean F_0 contours for stimuli with first syllables having (a) Tone 1 (b) Tone 2 (c) Tone 3 (d) Tone 4

to be a tendency for high onsets in the second syllable to correlate with lower than average F_0 in the first syllable, and for low onsets in the second syllable to correlate with higher than average F_0 in the first syllable, that is, anticipatory dissimilation as predicted by Hypothesis E. The results of the

ANOVAs for testing Hypothesis E are displayed in Table 6.

Table 6: ANOVA test of anticipatory dissimilation

Vowel Initial	Df	F value	Pr(>F)
tone	3	155.8705	<2e-16 ***
post-tone onset	1	1.3491	0.2470
tone x onset	3	0.3382	0.7977
onset effect: 0.20 semi-tones			
Vowel Medial	Df	F value	Pr(>F)
tone	3	213.6601	< 2.2e-16 ***
post-tone onset	1	4.3235	0.039024 *
tone x onset	3	5.0262	0.002283 **
onset effect: 0.36 semi-tones			
Vowel Final	Df	F value	Pr(>F)
tone	3	82.7519	< 2.2e-16 ***
post-tone onset	1	1.8234	0.178629
tone x onset	3	5.2036	0.001812 **
onset effect: 0.31 semi-tones			
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1			

The effect of the following tonal onset is statistically significant only at the midpoint of the syllable. There are also highly statistically significant interactions between tone and onset at the medial and final points. A Tukey post hoc test shows that this interaction is primarily in differences between Tone 1 and Tone 3 and between Tone 1 and Tone 4.

4.3.2 Discussion

The coarticulation results generally confirm Hypotheses D and E. There is statistically significant assimilation in F_0 from the first syllable offset to the next syllable at the beginning of the second vowel, and there is statistically significant dissimilation in F_0 of the first syllable from the onset of the second syllable, in the middle of the first vowel. However, the details of this coarticulation seem to be different from that reported by Xu (1997) for Beijing Mandarin or by Gu and Lee (2007) for Cantonese. Whereas Xu found the carry-over coarticulation effect remaining assimilatory into the third syllable, Gu and Lee found it switching from assimilatory do dissimilatory between the second and third syllables. Inspection of the plots in Figure 8 suggests that the coarticulation effect in this data switches from assimilatory to dissimilatory in the middle of the second syllable, but the ANOVAs indicate that this effect is not statistically significant. A study with higher resolving power could more conclusively determine the reliability of the effect.

The results of the post hoc tests might be evidence of the difference that Xu observed between high and low targets, that high targets were more influenced by coarticulation than low targets are. However, it might also be that the interaction is a consequence of the withheld emphmǎmǎ and emphmàmǎ data.

5 Conclusion

We started this study with several aims: (a) to characterise the tonal contours of Singapore Mandarin, and to compare these with the contours of Beijing Mandarin and Taiwan Mandarin; (b) to explore the tone sandhi patterns in

Singapore Mandarin, and (c) to determine the effects of tonal coarticulation in Singapore Mandarin. Due to the limitation of availability of speakers, this study was based on a small sample of four L2 speakers of Singapore Mandarin, and our results should not be taken to be characteristic of Singapore Mandarin in general. Nonetheless, as a pilot study, this opportunity outlines some areas worthy of pursuit in future research.

The results of Experiment 1 clearly show that despite some similarities to the other varieties, the tones of Singapore Mandarin are identical to neither Beijing Mandarin nor Taiwan Mandarin. In terms of relative tonal duration, Singapore Mandarin tones pattern with neither of the other two varieties: while the relative duration of the tones in Beijing Mandarin is T3>T2>T1>T4 in descending order and that of Taiwan Mandarin is T2>T4>T1>T3, that of Singapore Mandarin is T1>T2>T3>T4. With respect to tonal countours, only Tone 1 is similar across all three varieties; Tone 2 in Singapore Mandarin is similar to that of Beijing Mandarin; Tone 3, on the other hand, is more like that of Taiwan Mandarin; Tone 4 has a different contour in Singapore Mandarin compared to the contour shared by Beijing and Taiwan Mandarin. Internally to the variety, the inter-speaker variation in the phonetic realisation of Tones 2, 3, and 4 suggest that Singapore Mandarin tolerates much variation in the transition between relatively stable onset and offset targets, and that the phonological representation of the four tones in Singapore Mandarin is cast solely in terms of onset and offset values.

The results of Experiment 2 show that Singapore Mandarin has the Tone 3 sandhi found in other dialects of Standard Mandarin, as well as suggesting a gender-related sandhi affecting Tone 2 when followed by Tone 4.

In addition, the coarticulation data from Experiment 2 show that the general pattern reported for Beijing Mandarin and Cantonese, of carry-over assimilation and anticipatory dissimilation in F_0 coarticulation, is also found in Singapore Mandarin.

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