

## ASYMMETRY IN CONTEXTUAL TONAL VARIATION IN MANDARIN

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It has been long known that the four lexical tones in Mandarin are subject to contextual variation in connected speech. Most of the contextual tonal variation reported to date (not including phonological variation such as tone sandhi) is assimilatory in nature. In this study, however, both assimilation and dissimilation are found in contextual tonal variation in Mandarin. Four Mandarin speakers produced the disyllabic sequences of /mama/ with all the sixteen possible bitonal combinations of the four lexical tones of Mandarin in four different carrier sentences.  $F_0$  measurements were obtained by measuring the distance between adjacent vocal cycles in the wave form and then transforming the measurements into  $F_0$  values. The obtained  $F_0$  curves were smoothed and normalized so that comparisons among different tonal contexts would be more straightforward. It was found that carryover contextual effect, i.e., influence of a tone on the following tone, is assimilatory in nature, whereas the anticipatory effect is mostly dissimilatory. In both cases, the actualization of a tone varies depending on the immediately adjacent tonal values rather than on the entire tone contour of the neighboring tone. While a low ending value in a tone tends to lower the  $F_0$  value of the following tone, a low starting value in a tone tends to raise the  $F_0$  value of the preceding tone. While the assimilatory tonal variation can be accounted for by coarticulation, the exact mechanism of the anticipatory tonal dissimilation is less clear. Several accounts for the anticipatory tonal dissimilation are discussed, including phonological deletion, wide-swing, limit of low pitch register, and counteraction of declination. The data seem to be most in accord with the last two accounts.

**Key words:** Speech Production in Chinese; Tonal Coarticulation; Assimilation & Dissimilation

### Introduction

Of the various contextual tonal variations found in tone languages, two kinds have been mostly discussed, namely, phonological tone sandhi and phonetic tonal coarticulation. A phonological tone sandhi has two characteristics: a) the tonal change

involved is categorical, and b) the change often can not be explained by any simple phonetic mechanism. The tone sandhi involving Tone 3 in Mandarin is a good example of phonological tone sandhi. When two Tone 3's follow one another within the same rhythmic unit or prosodic phrase, the first Tone 3 changes into Tone 2 (Chao, 1956, 1968). Perceptually, the Tone 2 derived from an underlying Tone 3 is indistinct from the underlying Tone 2 (Wang & Li, 1967), indicating a merge of tone categories at the surface phonetic level. Although there have been many attempts to find a phonetic mechanism for this tone sandhi, none of them was successful. In fact, it has been argued that this particular sandhi is probably due to historical changes because other dialects of Mandarin share similar sandhi rules, but the Tone 3's involved in those dialects have different tonal values from the Tone 3 in Beijing Mandarin (Wu, 1984).

Tonal variation due to coarticulation, on the other hand, is non-categorical and is explainable in phonetic terms. An example in Mandarin is the Tone 2 variation in three-syllable words or phrases. According to Chao (1948, 1968), at conversational speed, a Tone 2 on the second syllable in a three-syllable word or phrase changes into Tone 1 if it is preceded by Tone 1 or Tone 2 and followed by any other tone except the neutral tone. Recent studies found that this kind of Tone 2 variation is non-categorical both acoustically and perceptually (Shih, 1992; Xu, in print). Acoustically, Shih (1992) found that although some of the Tone 2 contours approximated those of Tone 1 in the context of Tone 1 — Tone 1, the measured  $F_0$  values of the two tones were different even when the speech style is the most casual (during conversation). She also found that the  $F_0$  variation in Tone 2 was gradient, ranging from bearing the most resemblance to Tone 1 when produced during conversation to having the least resemblance when produced in isolation, with those produced in read sentences bearing a moderate resemblance. In a recent study (Xu, in print), it was found that Mandarin listeners heard the Tone 2 tokens as Tone 2 most of the time in the context of Tone 1 / 2 — Tone 2 / 3 despite the severe deviation in  $F_0$  contour from its canonical form due to the influence of the tonal contexts. This indicates that, as heard by the listeners, the speaker did not produce a tone that is different from the underlying Tone 2 despite its distorted surface value. Hence, no change of tone categories was involved. In the same study, it was also found that those variations in Tone 2 was assimilatory in nature and thus can be explained in terms of coarticulation between adjacent tones.

The original purpose of the present study was to further examine the details of the coarticulatory patterns between adjacent tones in Mandarin. It was expected that except for the phonological tone sandhi involving Tone 3, all the variation would be due to assimilation to the tonal contexts and thus can be explained in coarticulatory terms. As it turned out, somewhat surprisingly, however, both assimilatory and dissimilatory effects were found.

Previous phonetic studies on the coarticulation of tones in the tone languages of East Asia (Abramson, 1979; Han & Kim, 1974; Ho, 1976; Lin, Lin, Xia, & Cao, 1980; Lin, 1984; Shen, 1990; Shih, 1986, 1992; Wu, 1984, 1988) found that tonal variation is

mostly assimilatory in nature. Tonal dissimilation has never been systematically reported. However, in at least a few studies, evidence of similar tonal dissimilation can be seen in the data. I will discuss the details of the evidence when I later compare my data with the data in those studies.

## Acoustic analysis

### Material

Two main reading lists were used for production of the Mandarin tones. List A, as shown in Table 1, consists of the syllable /ma/ with the four Mandarin lexical tones.

Table 1. List A — Tones in monosyllables.

Pinyin:	mā	má	mǎ	mà
Character:	妈	麻	马	骂

List B, as shown in Table 2, consists of sixteen disyllabic sequences of /mama/ that make up all the possible bitonal combinations of the four lexical tones of Mandarin:

Table 2. List B — Tones in disyllabic sequences

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

The use of nasals as initial consonants is for examining the continuous trajectory of  $F_0$  contours, and at the same time, nasal-vowel boundaries are relatively easy to determine in the wave form.

The monosyllables would be produced in isolation, and the disyllabic items would be produced in four different carrier sentences as follows:

Carrier 1:	我教_____联络 Wǒ jiāo_____liánlùè.	'I teach___ to communicate.'
Carrier 2:	我教_____练习 Wǒ jiāo_____liànxí.	'I teach___ to practice.'
Carrier 3:	我叫_____联络 Wǒ jiào_____liánlùè.	'I tell___ to communicate.'
Carrier 4:	我叫_____练习 Wǒ jiào_____liànxí.	'I tell___ to practice.'

These carriers were designed in such a way that their phonetic as well as syntactic structures were very similar, except for their tones. There were two different pre-target syllables, /jiao/ and /jiao/, thus the tone before the target unit has either a high pitch ending or a low pitch ending. Likewise, the tones on the two post-target syllables start either at a low pitch, as in /lian/, or at a high pitch, as in /lian/ and the rest of the syllable structures in the two syllables are the same.

### Recording

Four native speakers of Mandarin, all of them male, produced those sentences. Three of the speakers were born and raised in Beijing, and so were native speakers of Beijing Mandarin. The fourth speaker (the author) is a native speaker of Standard Chinese, the official dialect that has the same phonetic system as Beijing Mandarin.

The disyllabic sequences were printed in Chinese in two different orders: a) the same order as in the list shown above; b) the reversed order. The carrier sentences were printed in Chinese on each of the two reading sheets below those disyllabic sequences.

A pre-recorded pacing tape was used to control the speaking rate of the speakers. On the tape were groups of six beeps with intervals of three seconds. The beginning of each group was signaled by a double beep, and the end of each group by an extra long beep.

The speakers first produced the monosyllable /ma/ with the four lexical tones in isolation. They then produced all the 16 disyllabic sequences without any carrier. Finally, they produced all the disyllabic sequences in each of the four carrier sentences. The speakers repeated each item six times, each repetition following a beep played from the pacing tape. The speakers were asked to make all their production as natural as possible. However, for the sequence 妈妈 (mother), they were told to say it with the same stress pattern as the other sequences instead of the usual trochee stress pattern for the word for "mother". It turned out that they had no difficulty in following this instruction.

### F<sub>0</sub> measurement

The utterances were digitized by the Haskins PCM system (Whalen, Wiley, Rubin, & Cooper, 1990) at a sampling rate of 20 KHz. F<sub>0</sub> extraction were carried out manually. The wave form of an utterance was displayed on the computer screen. Each pitch cycle in the wave form of a disyllabic sequence (no measurements were obtained for the carrier sentences) was marked with a label. The distances between adjacent labels were recorded in a file. Those files were processed by a separate computer program written by the author. The program transforms the distances between the neighboring labels into F<sub>0</sub> values. The F<sub>0</sub> curves obtained were smoothed using a simple window function that eliminates any bumps or sharp edges in the F<sub>0</sub> contour that are greater than two Hertz. Each F<sub>0</sub> curve was then time-normalized within each of the four segments in the disyllabic sequence, namely, the first nasal, the first vowel, the second nasal, and the second vowel. Ten F<sub>0</sub> frames were obtained for each of the two nasal segments; and twenty F<sub>0</sub> frames were obtained for each of the two vocalic segments.

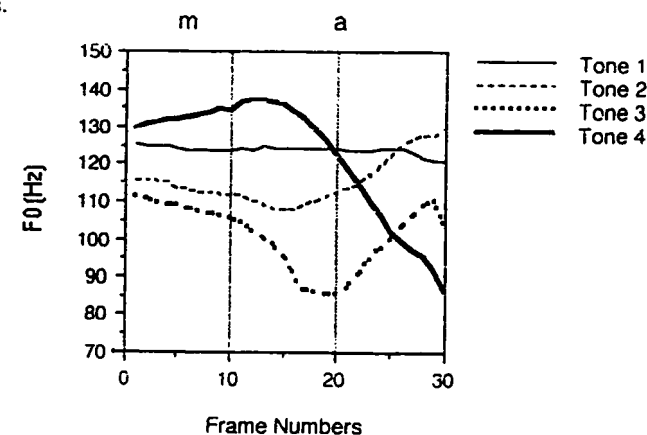


Figure 1. Mean F<sub>0</sub> contours of four Mandarin tones produced in isolation.

Figure 1 shows the F<sub>0</sub> contour for the syllable /ma/ in four different tones averaged over all the tokens produced by the four speakers. The abscissa is frame numbers. The distance between frames are in normalized time. The nasal segment consists of 10 frames, while the vocalic segment consists of 20 frames. The ordinate is F<sub>0</sub> value in Hertz.

Figure 2 shows variations of F<sub>0</sub> contours in the tones of the second syllable due to the influence of the preceding tones. The two nasal segments each consists of 10 frames, while the two vocalic segments each consists of 20 frames. To bring out the effect more clearly, when the tone of the first syllable has a high ending value, the curve is drawn with a thin line; when it has a low ending value, the curve is drawn with a thick line.

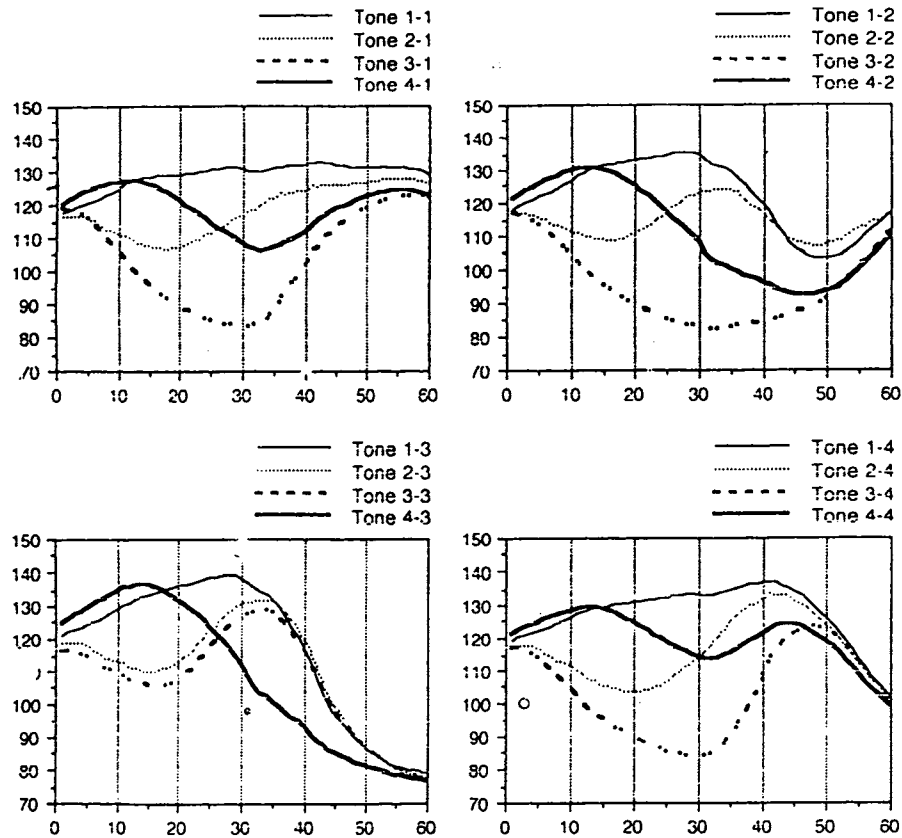


Figure 2.  $F_0$  contours of the four lexical tones under carryover tonal influence. The abscissas are frame numbers. The ordinates are  $F_0$  in Hertz.

The carryover effect in Figure 2 is apparent. When the preceding tone ends at a high  $F_0$  value, not only are the  $F_0$  values during the second initial nasal segment higher, but also the starting  $F_0$  values of the second vocalic segment are higher. When the tone of the second syllable is Tone 1 or 2, the difference can be seen all the way to the end of the second vocalic segment.

Figure 3 shows the  $F_0$  variations of the tone of the first syllable due to the influence of the second syllable. When the following tone has a high starting  $F_0$  value, the curve is drawn with a solid line; when the following tone has a low starting  $F_0$  value, the curve is drawn with a dashed line.

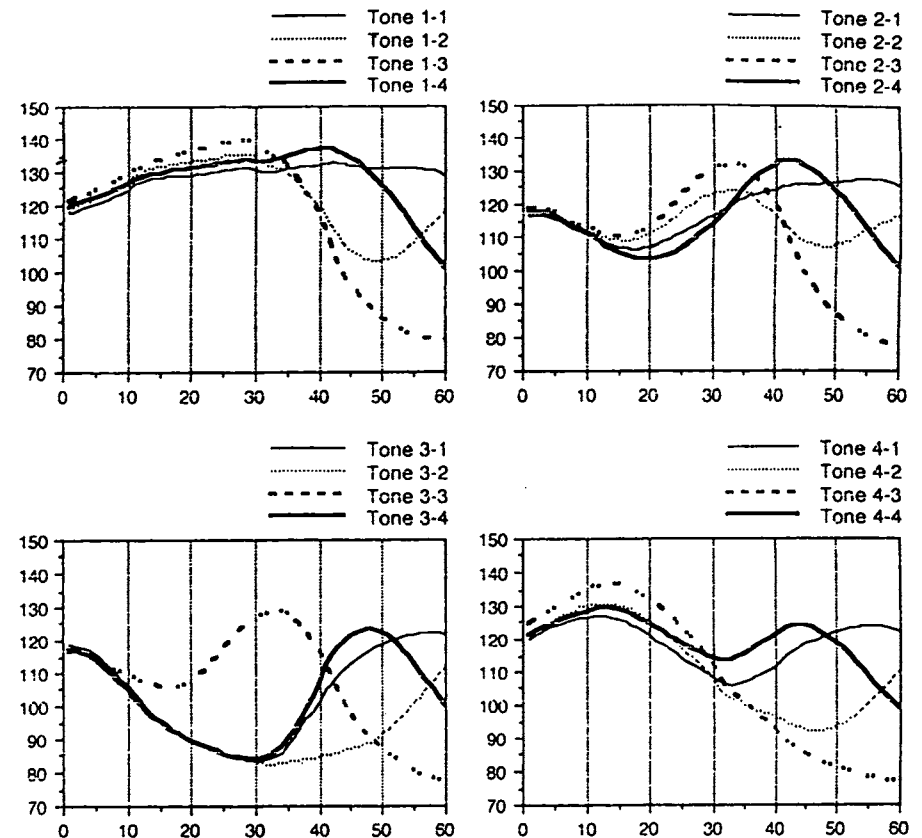


Figure 3.  $F_0$  contours of the four lexical tones under anticipatory tonal influence.

Instead of anticipatory assimilation as one would expect, what we see here is anticipatory dissimilation. When the tone of the first syllable is Tone 1, both dashed lines are higher than the solid lines in the first vocalic segment (Frames 11-30), and the differences remain throughout the entire vocalic segment. When the tone of the first syllable is Tone 2, the same trend can be seen, and the differences remain until almost half way through the second nasal segment (Frames 11-35). When the tone of the first syllable is Tone 4, similar trend can be seen. The differences are seen throughout the first vocalic segment when followed by Tone 3; and about half way through the first vocalic segment when followed by Tone 2. When the preceding tone

is Tone 3, however, no effect of the following tone can be seen except for the apparent tone sandhi when the following tone is also Tone 3.

### Statistical analysis

To verify the statistical significance of the anticipatory dissimilation and carryover assimilation seen in the  $F_0$  contours, statistical analyses were performed with four measurements as dependent variables: 1) Maxfo : Maximum  $F_0$  in each of the four segments involved, namely, the first and second nasal segments, and the first and second vocalic segments; 2) Minfo : Minimum  $F_0$  in each of those four segments; 3) Diffo : Difference between the maximum and minimum  $F_0$  in each of four segments; and 4) Meanfo : Mean  $F_0$  of each of those segments. For the tone of the second syllable, the independent variable is the ending pitch of the first syllable: High for Tone 1 and Tone 2, and Low for Tone 3 and Tone 4. For the tone of the first syllable, the independent variable is the starting pitch height of the second syllable: High for Tone 1 and Tone 4, and Low for Tone 2 and Tone 3. Tables 3 and 4 show the results of the ANOVA. The effect tested for the tone of the second syllable is carryover assimilation (Table 3), i.e., whether the  $F_0$  value of the second syllable is raised by a high ending pitch but lowered by a low ending pitch of the first syllable. The effect tested for the tone of the first syllable is anticipatory dissimilation (Table 4), i.e., whether the  $F_0$  value of the first syllable is raised by a low starting pitch but lowered by a high starting  $F_0$  of the second syllable. In the present paper, only the effects on the vocalic segments of the two syllables are discussed. So, the statistics listed in the following two tables and later ones do not include any effects on the nasal segments of the two syllables.

Table 3. ANOVA Results for carryover effects.

Tone	Maxfo		Meanfo		Minfo		Diffo	
	F	P	F	P	F	P	F	P
Tone 1	5.41	.0345	11.52	.0040	22.94	.0002	54.42	.0001
Tone 2	7.02	.0182	30.00	.0001	38.75	.0001	28.93	.0001
Tone 3	42.59	.0003	12.41	.0097	.06	.8102	43.19	.0003
Tone 4	11.45	.0041	6.67	.0208	3.20	.0937	12.75	.0028

df: 15 for Tone 1, 2, and 4; 7 for Tone 3;  
Independent Variable: Ending  $F_0$  value (H / L) of the first syllable.

In Table 3, most of the effects are highly significant. The Minfo of Tone 3 and 4 are not affected by carryover effects at all. The carryover effects on Maxfo of Tone 1 and 2, and on Meanfo of Tone 4, though significant at .05 level, do not reach .01 level. Based on the comparison of the averaged curves shown in Figure 1, we know that the carryover effects are all assimilatory, i.e., the higher the ending value of the preceding tone, the higher the value of the following tone.

Table 4. ANOVA Results for anticipatory effects.

Tone	Maxfo		Meanfo		Minfo		Diffo	
	F	P	F	P	F	P	F	P
Tone 1	33.77	.0001	51.44	.0001	40.44	.0001	6.56	.0217
Tone 2	50.24	.0001	37.17	.0001	17.29	.0008	38.11	.0001
Tone 3	2.62	.1495	.60	.4649	.48	.5095	.13	.7318
Tone 4	29.66	.0001	18.88	.0006	1.70	.2116	38.56	.0001

df: 15 for Tone 1, 2, and 4; 7 for Tone 3;  
Independent Variable: Starting  $F_0$  value (H / L) of the second syllable.

In Table 4, all the effects on Tone 1 and 2 are highly significant except on Diffo of Tone 1 which is significant at .05 level. For Tone 4, the anticipatory effect is significant on all the  $F_0$  measurements except Minfo. None of the effects are significant for Tone 3.

The statistics demonstrate that the anticipatory dissimilation seen in Figure 2 is real: a tone that begins with a low value raises the Maxfo, Diffo, and the Meanfo of the preceding tone unless it is Tone 3; a lower beginning value of a tone also raises the Minfo of the preceding Tone 1 and 2.

While carryover assimilation is hardly surprising, anticipatory dissimilation is quite unexpected. As mentioned at the beginning of the his paper, this phenomenon has never been systematically reported, except for some evidence in the data in a few studies. One of them is by Shih (1986). She measured the starting and ending  $F_0$  of the four Mandarin lexical tones in disyllabic words. The following table shows her measurements of the  $F_0$  values of the first syllable when followed by different tones.

Table 5. Starting and ending  $F_0$  values of the /fu/ in four tones when followed by different tones as measured by Shih (1986).

	fū	fú	fǔ	fù
Isolation	266-266	211-253	214-154	287-159
Before Tone 1	258-270	219-245	213-176	299-218
Before Tone 2	274-291	216-257	223-168	300-227
Before Tone 3	273-290	223-281	—	310-238
Before Tone 4	268-286	216-243	225-178	300-227

Although her speaker's Mandarin is that of Taiwan version, the  $F_0$  values shown in this table are surprisingly similar to those obtained in the present study.

Shen (1990) also noticed that "Tone 1 and 2 have the highest overall tonal values when preceding ... Tones 2 and 3".

In a recent study (Gandour, 1992), anticipatory tonal dissimilation was found for the falling tone in Thai. Although no systematic conclusion was reached concerning anticipatory dissimilation because the falling tone was the only tone checked for anticipatory effect when followed by different tones, the trend is similar to what is seen in the present study.

More interestingly, the raising of  $F_0$  before a low tonal target seems to be not unique to the East Asian tone languages. Recently, a similar phenomenon was found in one of the African tone languages, Yoruba (Connell & Ladd, 1990; Laniran, 1992).

### Discussion and further analysis

The  $F_0$  measurements of the present study and some of the previous ones demonstrate that the contextual tonal variations in disyllabic tone patterns in Mandarin and maybe in some other tone languages in East Asia is asymmetrical: while the carryover effect is mostly assimilatory, the anticipatory effect is mostly dissimilatory. The phenomenon of assimilation has been much discussed in the literature, so much so that there is no need to cite any particular reference here. Dissimilation, however, has almost never been discussed as a phonetic process. The literature provides us with only occasional discussion over some aspects of the dissimilation process similar to those found in the present study. Shih (1986), for example, states that

When a H target follows, the rising slope of a tone 2 turns out to be the interpolation from its M target to the H of the next syllable, rather than to its own H. This phenomenon suggests that the final H of a tone 2 is deleted, or absorbed by the next H target. Tone 2 seems to end lower in this context only because the value at the syllable boundary does not represent the H target, but a point on the rising slope. When the following target is L, the position of the initial H is unaffected and the pitch value at the end of the syllable reflects the H value.

This deletion account seems to take into consideration only the anticipatory variation in Tone 2. The anticipatory tonal dissimilation in Mandarin, however, seems to apply to all the tones that have at least one high pitch target: Tone 1, 2 and 4. It would be hard to argue that any of the two high targets in Tone 1 is deleted when followed by Tone 2 and 3 based either on the data of the present study or on hers (Shih, 1986). It is even harder to attribute the  $F_0$  variation in the preceding Tone 4 to deletion of the high target when it is followed by Tone 1 or another Tone 4.

A second account is by Gandour (1992) who states that when a falling tone is followed by a low tonal target in Thai,

... the transition is from a tone that traverses the high region of the voice range to tones that initially traverse the low region. This transition requires complex adjustments of the vocal folds. Because of vocal fold dynamics, one may speculate it is easier in some articulatory sense to move from an even higher  $F_0$  to an extremely low  $F_0$ . This vocal fold adjustment is analogous to what happens when a semi-trailer swings wide to make a sharp right or left turn. The extra wide turn facilitates the movement from a street going in one direction to a street cutting off at a 90 degree angle. The anticipatory effects on the slope of the preceding falling tone are believed to follow as a consequence of the adjustments in height. From a given height to a fixed  $F_0$  onset, the slope must necessarily be steeper from a higher  $F_0$ . Back to the semi-trailer analogy, the angle of the turn varies as a direct consequence of the wider swing around the corner.

This wide-swing account compares transition between pitch registers to the turning of a semi-trailer. Following this analogy, a low-to-high  $F_0$  transition should be just the same as a high-to-low transition, which means that, not only should a high pitch target be raised by a following low pitch target, but also a low pitch target should be lowered by a following high pitch target. However, neither is the final  $F_0$  in the Mandarin falling and low tones affected by the starting pitch of the following tone (cf. Figure 3), nor is the final  $F_0$  of the Thai falling tone lowered by the high initial  $F_0$  of a following falling tone (Gandour, 1992). So, in general, the wide-swing account cannot explain why the high pitch range is affected more than the low pitch range by the following tone.

It seems that an adequate account for anticipatory tonal dissimilation ought to be able to explain why carryover assimilation as well as anticipatory dissimilation affect the high pitch range more than the low pitch range. This taken into consideration, two alternative accounts are suggested as follows.

a) It is more difficult to reach a low tonal target than a high tonal target due to articulatory constraints. As an alternative, the upper range in the preceding tone is extended. One problem with this account is that, although the starting pitch of the rising tone does not reach the lower threshold, it nevertheless raises the preceding tone. However, it may be assumed that the difficulty in reaching a low pitch target is relative: the lower the pitch, the more difficult it is to reach it. Hence, because the low target for the low tone is lower than that of the rising tone, greater effort is needed to expand the upper range of the previous tone. A physiological support for this assumption may be found in Erickson (1976). She observed that while the production of a low pitch involves the activities of the strap muscles (mainly, thyrohyoid, sternohyoid and sternothyroid), those muscles only contribute actively to lowering  $F_0$  when the pitch is to drop below a threshold level, usually near the midrange. This indicates that to reach the lower bottom, extra effort by the speaker is needed.

b) Alternatively, the anticipatory dissimilation is to counteract declination, "the tendency

of pitch to drift downwards over the course of an intonation group", (Pierrehumbert, 1979), which has been found in many languages including Mandarin (Gårding, 1987; Maeda, 1976; Hart, 1973). Because the normal declination is already going from high to low, to produce the tonal differences, there is a need to make the tonal patterns distinct from the declination contour. When the tonal pattern is HH or LH across the tonal boundary, it is already different from the intonation. When the tonal pattern is HL or HM across the tonal boundary, however, there is a potential danger of confusing the tonal pattern with the declination pattern. To reduce this potential danger, the difference between the H and L target is exaggerated. However, due to the physical limit of the lower threshold, this exaggeration is accomplished by fully implementing the H target rather than by lowering the L target.

A problem with this account, however, is that according to the hypothesis, the danger of tonal differences being confused with declination should be greater in a sequence of HM than in HL. Yet, in the  $F_0$  analysis, it was found that the  $F_0$  values were higher before a low tone than before a rising tone, and the low tone has a lower pitch than the rising tone when produced in isolation. A possible explanation might be found in another finding by Pierrehumbert (1979) that "a greater correction for declination was made for wide pitch range stimuli than for narrow pitch range stimuli." Since the pitch range in HL is greater than that in HM, the speaker expects greater correction by the listener, hence, he would make greater effort in counteracting this expected correction.

Pending further investigations, the last two accounts seem equally plausible for the time being, because both of them can accommodate most of the data. Everything considered, account (c) is slightly more favored over account (d), because the latter has to presume speaker's sensitivity to  $F_0$  declination, which is yet to be proven.

### Summary

In the present study, both assimilation and dissimilation are found in contextual tonal variation in Mandarin. It was found that carryover contextual effects, i.e., influence of the preceding tone on the following tone, are assimilatory in nature, whereas anticipatory effects are mostly dissimilatory. In both cases, the actualization of a tone varies depending on the immediately adjacent tonal values rather than on the entire tonal curve of the neighboring tone. While a low ending value in a preceding tone tends to lower the  $F_0$  value of the following tone, a low starting value in a following tone tends to raise the  $F_0$  value of the preceding tone. While the assimilatory tonal variation can be accounted for by coarticulation, the exact mechanism of the anticipatory tonal dissimilation is less clear. Several accounts for the anticipatory tonal dissimilation are discussed, including phonological deletion, wide-swing, limit of low pitch register, and counteraction of declination. The data seem to be most in accord with the last two accounts.

### More remaining questions

The finding of asymmetry in contextual tonal variation, especially anticipatory dissimilation in Mandarin, though intriguing by itself, raises more questions to be answered and calls for further investigation.

First, does anticipatory and carryover effects interact with stress? If yes, how? Does stressing the preceding syllable enlarge or reduce anticipatory or carryover effect? What does stressing the following syllable interact with those two effects?

Second, what is the domain of the two effects? Is it possible that a stressed syllable will exert its influence beyond the adjacent syllable?

Finally, more supporting evidence for the limit-of-low-pitch-register account or for the counteraction account for the anticipatory dissimilation is needed. Or, if there isn't any, alternative accounts for the phenomenon are needed.

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