A Reconsideration of Universal Properties of Tonal Coarticulation*

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***Abstract*—Although many languages show similar properties in tonal coarticulation, some languages examined recently exhibit properties against previous findings. This study performed statistical analysis including one-way repeated measures ANOVA with Greenhouse-Geisser adjusted values and linear mixed effects models to explore properties of tonal coarticulation in Nanjing Chinese. The results show similar magnitude in carryover and anticipatory effects, inconsistent with most languages examined, and the results for the H/L asymmetry in Nanjing Chinese are not consistent with the literature either. The findings in this study and other recent studies contrary to previous beliefs call for further studies to enhance our understanding of the universality of tonal coarticulation.**

Keywords— tonal coarticulation, carryover effects, anticipatory effects, Nanjing Chinese, typology

I. INTRODUCTION

A. Properties of tonal coarticulation

Contextual variations of tones have been investigated in various languages including, among others, Thai [1, 2, 3], Mandarin Chinese [4, 5], and Cantonese [6]. In general, these studies agree that there are two main sources of tonal variations, namely the carryover (progressive) effect and the anticipatory (regressive) effect, where the carryover effect is claimed to exert more influence on tonal coarticulation than the anticipatory effect, either by a bigger magnitude, by a larger portion of the following syllable than the preceding syllable being affected, or by the carryover effects having fewer restrictions on tonal categories than the anticipatory effects since some tones do not allow anticipatory effects, as in Thai [3, 5, 7, 8].

Some characteristics of tonal coarticulation summarized by [9] are of interest in this study: 1) Most studies show the direction of tonal coarticulation can be both progressive and regressive; 2) The magnitude of progressive coarticulation is larger than regressive coarticulation; 3) Progressive coarticulation is assimilatory cross-linguistically, and regressive coarticulation is more language specific or even tone-related, which may be assimilatory or dissmilatory. 4) High and Low tones differ in tonal coarticulation. However, it is noteworthy some exceptions have been found in several languages. No significant magnitudes of contextual variation were found in Southern Min, because Southern Min tone sandhi suppresses tonal coarticulation [10]. An exception was also found in Kinyarwanda [11], where there is substantial anticipatory coarticulation, and the carryover coarticulation may not be any greater than it. Furthermore, it is also reported that Malaysian Hokkien exhibits some unusual features different from other reported languages discussed here [12]. The progressive and regressive effects are similar in magnitude, and progressive dissmilation is also detected, where most languages examined in the literature only show progressive assimilation. Moreover, progressive dissimilation in disyllabic tonal combinations was also found with T1 (41) on the second syllable in Tianjin Chinese, where a higher offset leads to a lower pitch than a mid-offset [9].

Although tonal coarticulation has been investigated extensively, a consensus has yet to emerge with regard to its cross-linguistic patterns. In effect, with an increase in the number of languages examined, the previously identified universal trend has been challenged, such as the magnitude differences in carryover and anticipatory effects [9, 10, 11, 12]. In this paper, we attempted to examine properties of anticipatory and carryover effects in Nanjing Chinese, their differences in magnitudes and interactions with low/high tone types and whether there are properties against previous beliefs of universality of tonal coarticulation.

B. Background of Nanjing Chinese

The city Nanjing locates in the southwest part of Jiangsu province, along the east coast of China [13, 14]. Nanjing Chinese spoken in this area belong to Jianghuai Mandarin [15]. There are five basic tones in Nanjing Chinese, but the tone values in the Chao's five-point scale [16] are transcribed slightly differently in the literature: Tone 1 (31/41), Tone 2 (24/13), Tone 3 (22/212/11), Tone 4 (44), Tone 5 (5/55) [13, 17, 18].

In addition to different transcription in monotones, there are some discrepancies about tone sandhi rules in Nanjing Chinese. Based on impressionistic data, researchers differ in the description of tone sandhi rules. Liu proposes six tone sandhi rules [17], and Sun proposes five [18]. Liu's proposal contains one more rule for the tonal combination T4. Moreover, Liu believes that T5 (5) turns into a derived tone with a tone value 3, whereas Sun believes that T5 turns into T4 (44) [17, 18]. The rest of the rules are described similarly with slight differences in transcription of monotones.

II. METHODS

In this study, we recruited and recorded a total of twelve native speakers of Nanjing Chinese (six females and six males). The participants were in the age range of 35~65 years

old, and have lived in Nanjing for most of their lives since birth. All the participants were recorded in a quiet room during the fieldwork, using a Marantz PMD 660 digital recorder with a Shure SM2 head-mounted microphone. The recordings were transferred to a PC with a sampling rate of 48kHz.

The stimuli selected in this study consist of 1500 disyllabic words (5 words * 25 combinations * 12 speakers) in Nanjing Chinese. The words recorded without a carrier phrase were analysed, since the effect of tonal coarticulation is yet unkown in Nanjing Chinese, and it is unknown whether the preceding and following tone in a carrier phrase will affect the pitch contour of the target words due to tonal coarticulation or tone sandhi. All the words are recorded at a normal speaking rate with proper pause in between, and the speakers were instructed to adhere to the same intonation pattern as for statements. Most monosyllables and disyllables are chosen from the Dictionary of the Nanjing Dialect [18], and consulted with native speakers of Nanjing Chinese.

After recording, the target words were first segmented manually, using Praat [19]. We used a Praat script to extract twenty f0 values spread evenly within each individual segment.

To examine potential carry-over effects, the second tone is held constant with varied first tones. For example, the tonal combinations of T1 + T1, T2 + T1, T3+ T1 etc. were compared, where the tone on the second syllable is controlled to be T1. In contrast, the first tone is held constant for an examination of anticipatory effects. A series of statistical analysis including descriptive statistics, repeated measures ANOVA, and linear mixed effects models were performed to explore the characteristics of the carryover and anticipatory effects.

III. Results

A. Carryover effects

The classification of H, M and L based on surface realization of tones is listed in Table 1. Figure 1 plots the combination T + T1 (T stands for any tone of T1, T2, T3, T4 and T5) as an example. The last combination T + T5 is excluded from the analysis because there are only two pairs that have not undergone tone sandhi.

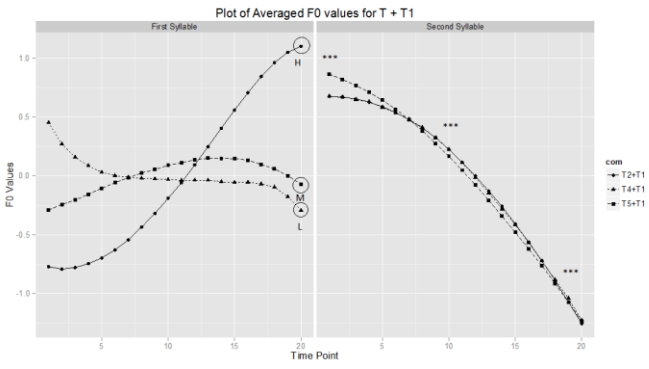

Fig. 1. Averaged f0 values of T + T1

The results of repeated measures ANOVA are summarized in Table 1. In all the combinations, the onsets of the second syllables are significantly different after H, M and L offsets, suggesting significant carryover effects. These effects are the most prominent at the onset of the second syllable, and shrink toward the end. The duration through which the carryover effect sustains do show some differences among the tone types of the second syllable. Specifically, tones starting with higher f0 values are affected longer by the carryover effect. The effect shows up throughout the second syllable for T4 (44) with statistical significance. However, the duration through which a Low tone target sustains is much shorter. In Nanjing Chinese, T3 (22/212/11) no longer shows significant carryover effects toward the end, though the midpoint of T3 still shows significant effects.

TABLE I. Classification of Tones for Examining Carryover Effects

Combination/ Second syllable position	Beginning	Mid	End
T + T1	F(57.67,	F(56.15,	F(51.97,
H: T2	115.33) =	112.30) =	103.93) =
M: T5	74.61	62.24	14.65
L: T4	p < 0.001***	p < 0.001***	p < 0.001***
T + T2	F(33.61,	F(33.87,	F (39.93,
H: T2	67.23) =	67.73) =	79.85) =
M: T3, T5	4.62	1.52	0.39
L: T1, T4	p = 0.03*	p = 0.22	p = 0.60
T + T3	F(45.89,	F(44.2,	F(48.33,
H: T2	91.79) =	88.40) =	96.66) =
M: T5	4.49	4.24	2.29
L: T1, T4	p = 0.02*	p = 0.03*	p = 0.12

A linear mixed model was used to examine if there is a possible linear relationship between the independent variable (five points of the first syllable) and the dependent variable (the onset of the second syllable). The word items with various consonants and vowels are modelled with a random effect. The results show that the linear relationship is significant and positive for all five tones. It suggests that the carryover effect in Nanjing Chinese is assimilatory for all tones. Again, tones starting with a higher value (T1 (31/41), T4 (44) and T5 (5/55)) show a steeper slope than tones with a lower onset (T2 (24/13) and T3 (22/212/11)), and thus a stronger carryover effect.

The maximum, minimum, mean and standard deviation of f0 values on five points of the second syllable (0%, 25%, 50%, 75%, 100%) for each tonal were calculated. In general, the standard deviation decreases toward the end of the syllable. Also, the magnitude of carryover effects differs among tonal types. Tones with higher onset such as T1 (31/41) and T4 (44) have larger standard deviation than lower onset T2 (24/13) and T3 (22/212/11), suggesting bigger carryover effects for High tones, which is also attested in the duration of the effect.

From the above analysis, the results show: 1) the duration through which the carryover effect sustains by the High tone

targets is longer than Low tones; 2) All the slopes in linear mixed effects models are positive, indicating an assimilatory carryover effect so that High tones elicit higher f0 values on the second syllables and vice versa; 3) High tones exhibit a bigger magnitude in the carryover effects than Low tones.

B. Anticipatory effects

The tonal combinations reported to have undergone tone sandhi are first excluded from examination.

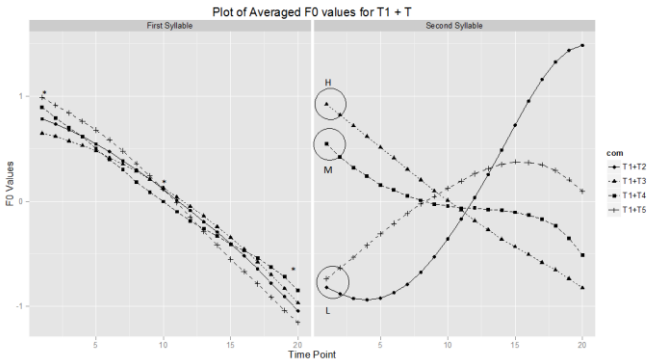

Fig. 2. Averaged f0 values of T1 + T

Table 2 presents the results of the repeated measures ANOVA, and Figure 2 plots averaged f0 contours of T1 + T as an example for examining anticipatory effects. The effects are most prominent at the end of the first syllable. Compared with the carryover effect where 75% of the points tested are significantly different, the anticipatory effect is slightly weaker, where 67% of the points tested are significant according to the H, M and L grouping of the second syllable. The anticipatory effect is reported to be weaker in most reported languages. We also tested the magnitude of the carryover and anticipatory effects by conducting a paired t-test on the standard deviation of the second syllable onset versus that of the first syllable offset. However, the result is not significant ($t(3) = 0.37$, $p = 0.74$), suggesting that the two effects are comparable when the magnitude is considered only.

Furthermore, the duration through which anticipatory effects sustain differs among tone types of the target first syllable. Anticipatory effects on T1 (31/41), T2 (24/13) and T3 (22/212/11) remains significant across vowels, whereas T4 (44) shows the effect only at the end of the first syllable, and no significance is found at the mid and beginning point of the tone. T5 (5/55) does not even show any significance in all the points tested. Low tones thus seem to be more affected by anticipatory effect than High tones, which is not so consistent with most of previous findings where Low tone targets are less affected.

TABLE II. CLASSIFICATION OF TONES FOR EXAMINING ANTICIPATORY EFFECTS

Combination/ Second syllable position	Beginning	Mid	End
T1 + T	F (65.05,	F (65.05,	F(68.47,
H: T3	130.11) =	130.11) =	136.94) =
M: T4	3.95	4.93	4.86
L: T5, T2	p = 0.045*	p = 0.03*	p = 0.02*
T2 + T	F(78.92,	F(86.63,	F(91.78,
H: T3	157.84) =	173.27) =	183.57) =
M: T4, T1	6.26	10.94	8.56
L: T2	p = 0.008**	p < 0.001***	p < 0.001***
T3 + T	F(48.43,	F(51.19,	F(55.24,
H: T4	96.85) =	102.37) =	110.48) =
M: T2	7.25	16.26	41.48
L: T5	p = 0.002**	p < 0.001***	p < 0.001***
T4 + T	F (71.27,	F(72.62,	F(74.89,
H: T3	142.54) =	145.24) =	149.77) =
M: T4, T1	1.29	0.74	11.71
L: T2	p = 0.27	p = 0.42	p < 0.001***
T5 + T	F(69.85,	F(67.38,	F(68.07,
H: T3, T1	139.70) =	134.76) =	136.13) =
M: T4	0.25	0.009	0.23
L: T2	p = 0.66	p = 0.94	p = 0.67

The linear mixed model shows that the slope values are exclusively positive, indicating a positive relationship between the offset of the first syllable and the five points of the second syllable. Therefore, Nanjing Chinese exhibits assimilatory anticipatory effect in general.

From the standard deviation, it can be inferred that the anticipatory effects are the most prominent at the end of the first syllable, and it shrinks toward the beginning except for T1 (31/41) and T4 (44), where there is a slightly decreasing trend toward the end. Across the tone types, we also found differences of magnitude in the anticipatory effects. When the first tone is a High tone such as T5 (5/55), the standard deviation is much higher than other types, indicating that T5 (5/55) is likely to be more affected by anticipatory effects. The rising T2 (24/13) with a relatively high offset also exhibits a fair amount of variation. Although High tones such as T5 (5/55) show less anticipatory effect as far as the duration is concerned, the magnitude of the effect does seem to be salient with a larger standard deviation. However, T4 (44) with higher f0 values shows a similar amount of effect as the Low tone T3 (22/212/11). Therefore, the magnitude does not consistently show the H/L asymmetry attested in other studies.

In sum, the anticipatory effect is slightly weaker than the carryover effect considering the duration effect, since the time points tested to be significant are fewer. However, the magnitude of the carryover and anticipatory effects are approximately equal with no statistical significance, which is consistent with findings in Malaysian Hokkien [12], but not with most reported languages. From the statistical analysis, we obtained the following results: 1) Low tones are subject to anticipatory effect for longer duration than High tones, which is not consistent with most languages reported in the literature, where High tones show more prominent anticipatory effect [6, 9]; 2) When the magnitude of the effect is examined, there are no obvious patterns of the H/L asymmetry proposed in the literature; 3) Nanjing Chinese exhibits an exclusively

assimilatory anticipatory effects, showing its language-specific property.

IV. Discussion

Most languages exhibit the trend that the carryover effect is greater than the anticipatory effect. However, this trend is not true for Malaysian Hokkein [12] and Nanjing Chinese in terms of magnitude because the two effects show similar magnitude, though the carryover effect exhibits longer duration than the anticipatory effect in both Malaysian Hokkein and Nanjing Chinese.

Specifically, the carryover effect is most prominent at the onset of the second syllable and shrinks toward the end. Tones starting with a higher F0 value are affected with longer duration by the carryover effect, and are thus better targets for the carryover effect, consistent with most languages reported in the literature. This trend is also confirmed by an analysis of magnitude, where carryover effects are bigger for High tones, consistent with findings in most languages. Furthermore, a linear mixed model reveals that the carryover effect is assimilatory.

Similar analyses were made to examine the anticipatory effect. As expected, the anticipatory effects are most prominent at the end of the first syllable, and shrinks toward the beginning. Moreover, there is a H/L tone asymmetry with respect to the duration of anticipatory effects on the target tones, where Low tones are better targets, not consistent with most languages in the literature. When the magnitude is examined, no consistent results are found concerning the H/L tone asymmetry, and the strength of anticipatory effects vary on each individual tone without an obvious H/L tone asymmetry pattern. Therefore, the inconsistent results found in Malaysian Hokkein and Nanjing Chinese question the H/L asymmetry for the carryover and anticipatory effects, which needs further studies on other languages.

These findings in Malaysian Hokkein and Nanjing Chinese, inconsistent with the literature, call for future studies to improve our understanding in the universality of those properties.

Specifically, based on the results in this study and other recent studies, we list the some new findings: 1) the magnitude of carryover and anticipatory effects may be comparable in some languages, where it is not the case that carryover effects are always stronger than anticipatory effects as in Nanjing Chinese and Malaysian Hokkein; 2) The carryover effect can be dissimilatory for some tonal pairs as in Tianjin Chinese and Malaysian Hokkein; 3) There may not be consistent results for the H/L asymmetry as in Nanjing Chinese and Malaysian Hokkein.

V. Conclusions

In this study, we explored properties of anticipatory and carryover effects by statistical analyses. The results reported above, together with recent studies challenge previous understandings about the characteristic of the two effects. Specifically, the carryover and anticipatory effects show similar magnitude rather than a bias toward stronger carryover effects. The H/L asymmetry is not so obvious in anticipatory effects on targets either.

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