AN UPDATED TYPOLOGY OF TONAL COARTICULATION PROPERTIES

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ABSTRACT

This study examines tonal coarticulation in Nanjing Chinese, and compares and contrasts its properties with those reported for other languages. Although many languages show similar characteristics, recent examinations of some languages have contradicted generalizations derived from previous findings. This study utilised descriptive statistics, linear mixed effects models, and Pearson's correlation to explore the properties of tonal coarticulation in Nanjing Chinese. The results conflict with previous generalizations that carryover effects are greater than anticipatory effects. Nanjing Chinese shows a similar magnitude in these two effects, as does Malaysian Hokkein (Chang and Hsieh 2012). Moreover, in Nanjing Chinese and Malaysian Hokkein, there are no consistent results for H/L asymmetry as has been reported for other languages. These diverging findings warrant further study to enhance our understanding of the universality of tonal coarticulation properties. Based on the findings thus far, we present an updated typology of the known properties of tonal coarticulation.

Key words: tonal coarticulation, carryover effects, anticipatory effects, Nanjing Chinese, typology

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1. INTRODUCTION

Contextual variations of tones have been investigated in various languages including, among others, Thai (Gandour, Potisuk, Dechongkit and Ponglorpisit 1992a, 1992b; Gandour, Potisuk and Dechongkit 1994), Mandarin Chinese (Shen 1990; Xu 1997), and Cantonese (Wong 2006). In general, these studies agree that there are two main sources of tonal variations, namely a carryover (progressive) effect and an anticipatory (regressive) effect. The carryover effect is claimed to exert more influence on tonal coarticulation than the anticipatory effect, either by a bigger magnitude or by influencing a larger portion of the following syllable than the preceding syllable being affected. Carryover effects tend to be assimilatory while anticipatory effects tend to be dissimilatory. Carryover effects may also exercise fewer restrictions on tonal categories than anticipatory effects, as in Thai (Xu 1997; Gandour et al. 1994; Potisuk, Gandour and Harper 1997; Brunelle 2009).

For example, Xu (1997) found that carryover effects are of a larger magnitude than anticipatory effects in Mandarin Chinese. A pattern of assimilatory carryover and dissimilatory anticipation was detected in disyllabic and trisyllabic Thai tones (Gandour et al. 1992a; Potisuk et al. 1997). Moreover, Yoruba shows local carryover assimilation, in addition to the well-known downstep and downdrift effects (Laniran and Clements 2003). More recently, Zhang and Liu (2011) found a greater progressive effect than regressive effect in Tianjin Chinese, a result similar to that for Mandarin Chinese. Zhang and Liu (2011) also note that regressive tonal coarticulation affects High tones more than Low tones in Tianjin Chinese, where T1 (21/11)[1] is treated as a Low tone, T2 (45/55) as a High tone, T3 (213/13/24) has a Low onset and High offset, and T4 (53) has a High offset and Low onset. However, Li and Chen (2016) argue against this conclusion since it is based only on restricted tonal combinations (T1 + T3, T2 + T3, T4 + T3 and T2 + T1). After an examination of all tonal combinations, Li and Chen (2016) found an anticipatory raising effect of T1.

[1] Tones are often described in Chao tone numbers (Chao 1930), where 1 stands for the lowest tone value, and 5 stands for the highest.

A thorough understanding of tonal coarticulation also benefits research on tone sandhi. Zhang and Liu (2011) note that tone sandhi rules in Tianjin Chinese are not hard to identify because the properties of tone sandhi rules and tonal coarticulation are different. For example, the tone sandhi rule T1 + T1 → T2 + T1 (41 + 41 → 34 + 41), raises the low offset of the first T1. In Tianjin Chinese, regressive tonal coarticulation has different properties from sandhi, affecting High tones more than Low tones. A clear understanding of tone coarticulation may help differentiate it from tone sandhi.

Although tonal coarticulation has been investigated extensively, a consensus has yet to emerge with regard to its cross-linguistic patterns. Currently, in light of the increase in the number of languages examined, challenges have been presented to trends, which were previously claimed to be universal. For example, contrary to previous claims, the differences of magnitude in carryover and anticipatory effects may be relatively equal and there may be no obvious H/L asymmetry with respect to progressive and regressive triggers (Lin 1988; Chang and Hsieh 2012; Myers 2003 as cited in Flemming 2011; Zhang and Liu 2011).

In this paper, we attempt to situate Nanjing Chinese in the current typology of tonal coarticulation by examining the properties of its anticipatory and carryover effects, as well as the differences in magnitudes and interactions with respect to Low/High tone types.

1.1 Background of Nanjing Chinese

The city of Nanjing is located in the southwest part of Jiangsu Province, which is situated along the east coast of China (Song 2006; Xu et al. 2007). Nanjing Chinese spoken in this area belongs to Jianghuai Mandarin (Chappell 2002).

There are five basic tones in Nanjing Chinese, transcribed slightly differently depending on the author: Tone 1 (31/41), Tone 2 (24/13), Tone 3 (22/212/11), Tone 4 (44), Tone 5 (5/55) (Sun 2003; Liu 1995, 1997; Song 2006). We plot normalized the F0 values of each monosyllabic tone as shown in Figure 1.

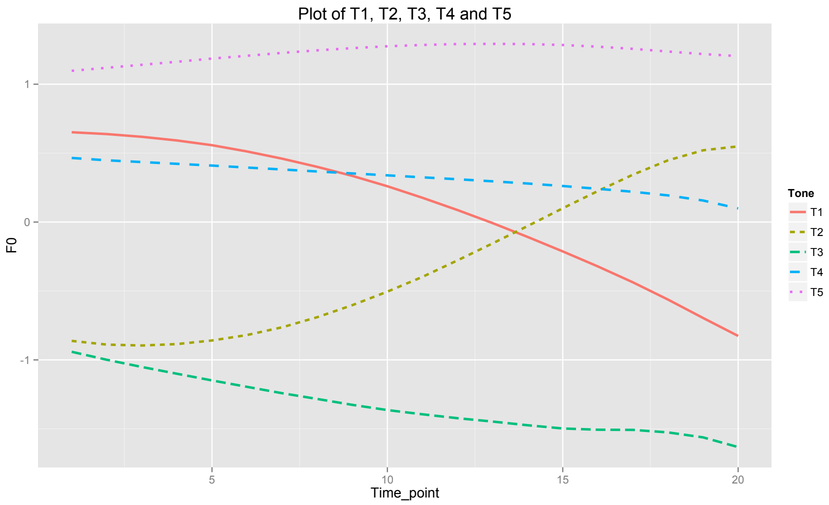

Figure 1. Normalized F0 values of Monosyllables

In addition to different transcriptions for monosyllabic tones, there are some discrepancies in the rendering of tone sandhi rules in Nanjing Chinese. Based on impressionistic data, researchers differ in the description of the tone sandhi rules as shown in Table 1. Liu (1995) proposes six tone sandhi rules, while Sun (2003) proposes five; Liu (1995)'s proposal includes an additional sandhi rule for the tonal combination T4 (44) + T5 (5). Moreover, Liu (1995) believes that T5 (5) turns into a derived tone with a pitch height of 3, whereas Sun (2003) believes that T5 turns into T4 (44). Table 1 lists a comparison of the rules offered by Liu (1995) and Sun (2003).

Table 1. A comparison of Liu's and Sun's sandhi rules

Liu (1995)	**Sun (2003)**
T1→T4/_T1 (41→44/_41)	T1→T4/_T1 (31→44/_31)
T2→T3/_T5 (24→11/_5)	T2→T3/_T5(13→22/_5)
T3→T2/_T1 (11→24/_41)	T3→T2/_T1(22→13/_31)
T3→T2/_T3 (11→24/_11)	T3→T1/_T3(22→31/_22)
T4→T1/_T5 (44→41/_5)	None
T5→3/_T5 (5→3/_5)	T5→T4/_T5 (5→44/_5)

1.2 A Typology of Tonal Coarticulation

Tone coarticulation is different from tone sandhi in that the former is phonetic and gradient, whereas the latter is phonological and categorical. Zhang and Liu (2011) argue that these two phenomena can be easily differentiated in Tianjin Chinese, because their properties are different. Tone sandhi rules are phonologically dissimilatory, and it is also in contrast to regressive tonal coarticulation, which affects High tones more than Low ones. However, it may be difficult to differentiate these two phenomena as their properties can be quite similar sometimes. More recently, quantitative methods have been proposed for modelling tone sandhi using underlying pitch targets, providing a potential means to differentiate sandhi from coarticulation (Chen, Wiltshire, and Li to appear). We summarize the characteristics of tone sandhi based on the proposals in the literature (Shen 1992; Chen 2000). First, tone sandhi has a relatively stable state across speakers. Second, there is a categorical shift from the original citation tone to another one or to a derived allotone, which is different from any citation tone. Third, there should be an influence on the entire tone, not merely at one edge or the other. Fourth, if a tone substitution is involved, the sandhi tone is perceptually non-distinct from the citation tone it turns into. For this study, we accepted tone sandhi rules proposed for Nanjing Chinese by Liu (1995) and Sun (2003), and keep them distinct from our data and analysis of tonal coarticulation.

Tone coarticulation effects are generally assumed to be subject to language-independent biomechanical restrictions (Shen 1992). Thus, it may be expected that a comparison of coarticulation effects across languages should yield similar patterns of behavior. Zhang and Liu (2011) summarized four properties of tonal coarticulation in Standard Chinese (e.g. Cheng 1986; Chao 1948, 1968; Zhang and Lai 2010), Taiwanese (e.g. Cheng 1968; Peng 1997), Vietnamese (e.g. Brunelle 2003, 2009), and Thai (e.g. Gandour et al. 1994). First, most studies find that the direction of tonal coarticulation can be both progressive and regressive. Second, the magnitude of the progressive coarticulation is larger than that of the regressive coarticulation. Third, progressive coarticulation is assimilatory cross-linguistically, and regressive coarticulation, which may be assimilatory or dissimilatory, is more language specific or even tone specific. Finally, High and Low tones differ in tonal coarticulation, whether they are the target or the trigger. Specifically, it is more likely for a Low tone to have a regressive dissimilation effect on a preceding High tone, and for a High tone to induce a progressive assimilation effect. However, it is noteworthy that some exceptions have been found in several languages. For Southern Min, Lin (1988) found no significant magnitudes of contextual variation, claiming that it is because Southern Min tone sandhi suppresses tonal coarticulation. Flemming (2011) also mentioned an exception found in Kinyarwanda, as described by Myers (2003), where the carryover coarticulation may not be greater than the substantial anticipatory coarticulation. Furthermore, Chang and Hsieh (2012) also reported that Malaysian Hokkien exhibits some unusual features. Contrary to claims that progressive coarticulation is generally larger in magnitude, the progressive and regressive effects are similar. In addition, progressive dissmilation is also detected, whereas most languages examined in the literature only show progressive assimilation. Moreover, progressive dissimilation in disyllabic tonal combinations with T1 (41) on the second syllable occurs in Tianjin Chinese, where a higher offset leads to a lower pitch than a mid offset (Zhang and Liu 2011). Specifically, they grouped T1 (21/11), T2 (45/55), and T3 (213/13/24) as tones with a high offset and T4 as a tone with a mid offset.

Table 2. A typology of tonal coarticulation

	Magnitude	**Assi. or dissi.**	**H/L asymmetry**	**Tone sandhi**
Cantonese (Wong, 2006)	P > R	P: assi.; R: dissi.	P assn target: L > H R dissn target: H > L	Restricted tonal changes
Yoruba (Laniran and Clements, 2003)	N. A.	P: assi.; R: dissi.	P assn trigger: only H reported R dissn trigger: only L reported	Tone spread (H and L tones combining into HL or LH)

Tianjin Chinese (Li and Liu, 1985; Shi, 1986; Zhang and Liu, 2011)	P > R(magnitude)	P: assi. with one exception(T+T1) R: dissi.	P assn trigger: H > L P assn target: H > L R dissn trigger: L > H R dissn target: H > L	a. T1(21/11) → T3(213/13/24)/__ T1(21/11) b. T3(213/13/24) →T2(45/55)/__ T3(213/13/24) c. T4(53) → T2(45/55)/__ T1(21/11) d. T4(53) → T1(21/11) /__ T4(53)
Malaysian Hokkein (Chang and Hsieh, 2012)	P ≈ R (magnitude) P > R (duration)	P: assi/dissi; R: assi/dissi;	P & R trigger: specific to particular tones	Base tones: T1 (33); T2 (23); T3 (52); T5 (21); T6 (21) (T5 and T6 are nearly merged) Sandhi tones T1'(33), T2'(21), T3'(34), T5'(53), T6'(21)

P = progressive; R = regressive; assi = assimilatory; dissi = dissmilatory; assn = assimilation; dissn = dissimilation

Table 2 summarizes only reported languages that did not appear in Zhang and Liu (2011)'s summary. Transcriptions are listed in the parenthesis after each tone in the tone sandhi rules. Matthews and Yip (1994) also describe tone changes in Cantonese, but as these are not regular enough to count as tone sandhi rules, they are not included here. Moreover, the question of H/L asymmetry is not addressed directly in Wong (2006), however, the information can be obtained by figures and the description provided therein, and is included.

In this study, we investigate the properties of tone coarticulation in Nanjing Chinese. We aim to answer four research questions: 1) Are the carryover effects stronger than anticipatory effects in Nanjing Chinese? 2) Are the two effects assimilatory or dissimilatory? 3) Is there a H/L asymmetry? 4) How can the typology be updated? The current study analysed the properties of tonal coarticulation in Nanjing Chinese, and compared its characteristics with those of previously described languages. It is the first study to investigate whether Nanjing Chinese matches the typological characteristics observed cross-linguistically or has exceptional characteristics of its own. This study thus fills a gap in the research, and updates the current typology.

2. METHODS

2.1 Subjects and Stimuli

We recruited and recorded twelve native speakers of Nanjing Chinese (six females and six males). Song (2006) and Chen and Wiltshire (2013) point out that there are differences in speech production by different age groups, therefore a specific age group was chosen for examination. The participants were in the age range of 35~65 years old, and had lived in Nanjing for most of their lives. Liu (1995) notes that speakers 75 years old and above by now speak an older version of Nanjing Chinese, while those in the age range of 35~65 speak a relatively new version of the dialect. All of the participants were recorded in a quiet room, using a Marantz PMD 660 digital recorder with a Shure SM2 head-mounted microphone, positioned to the corner of their mouth. The recordings were transferred to a PC with a sampling rate of 48kHz.

The stimuli selected in this study consist of a total of 660 monosyllabic tones (55 monosyllables * 12 participants) and 708 disyllabic words (59 words* 12 speakers) in Nanjing Chinese. The words recorded without a carrier phrase were analysed, since the effect of tonal coarticulation was as yet unknown in Nanjing Chinese at the time of the study, and it was unknown whether the preceding and following tone in a carrier phrase would affect the pitch contour of the target words due to tonal coarticulation or tone sandhi. All of the words were recorded at a normal speaking rate with a pause between each word, and the speakers were instructed to adhere to the same intonation pattern as for statements. The characteristics obtained in this study may inform future studies with carefully designed carrier phrases with balanced H, M, or L offset and onset for the words preceding and following the target monosyllables and disyllables, where the influences from the tonal coarticulation and tone sandhi may be minimized. Most of monosyllables and disyllables were chosen from the Dictionary of the Nanjing Dialect (Liu 1995), in consultation with native speakers of Nanjing Chinese.

2.2 F0 Extractions and Statistical Analysis

The target words were first segmented manually, using Praat (Boersma and Weenink 2013). Then, a Praat script was used to extract twenty time-normalized F0 values spread evenly within each individual segment, with a 25.6 ms analysis window. We followed the procedure of segmentation (Zhang et al. 2008 as cited in Jangjamras 2012; Jangjamras 2012). Each target vowel onset was defined as the first zero crossing at the beginning of voicing in the waveform. The vowel offset was defined as the downward zero crossing immediately following the final glottal pulse in the waveform.

To examine potential carryover effects, the tone of the second syllable was kept invariant and the first tone varied. For example, the tonal combinations of T1 + T1, T2 + T1, T3+ T1 etc. were compared, where the tone on the second syllable was controlled to be T1. In contrast, the tone on the first syllable was controlled for an examination of anticipatory effects. A series of statistical analyses including descriptive statistics, linear mixed effects models, and Pearson's correlation were performed to explore carryover and anticipatory effects.

First, in order to examine carryover effects, we tested whether F0 values at the onset (0%), 25%, mid (50%), 75%, and offset (100%) of the second syllables differ significantly when following different tones. We performed the same statistical test for all of the tonal combinations excluding the tone sandhi pairs. Linear mixed effects models were fitted and likelihood ratio tests were used to test the differences. The fixed effects included the gender of the speaker and a dummy variable coding different tonal combinations in which the target tone occurs (e.g. Aston, Chiou, and Evans 2010). The random effects included word items and speakers, if they showed significance by likelihood ratio tests. This procedure was to test whether the F0 values of five extracted time points differed for the same tone in different tonal combinations. If the F0 values of the same tone (e.g. T1) in different tonal combinations (e.g. T1+T1, T2+T1, T3+T1, etc.) show significant differences at the 0%, 25%, 50%, 75%, and 100% time points, then carryover effects are salient for a long duration. A similar procedure, *mutatis mutandis*, was applied to examine the anticipatory effects.

Second, we investigated whether the carryover and anticipatory effects show assimilatory or dissimilatory properties. Specifically, we fit linear mixed models, including random effects of words and speakers. The random effects were not included if they were statistically insignificant by a likelihood ratio test. To examine the carryover effects, the response variable of the linear mixed effects model included the F0 values extracted from the five time points (0%, 25%, 50%, 75%, 100%) of the second tone in each disyllable. Fixed effects included speaker gender and the F0 values of the offsets of the first tones. Similarly, to examine the anticipatory effect, the response variable was F0 values extracted from the five time points (0%, 25%, 50%, 75%, 100%) of the first tone in each disyllable. Fixed effects included speaker gender and the F0 values of the onsets of the second tones. After fitting the linear models, the Box-Pierce test (Box and Pierce 1970) of residuals suggested that the errors were not correlated, indicating no need to further model error correlation.

Third, in order to examine the magnitude of the carryover and anticipatory effects, we calculated the maximum, minimum, mean, and standard deviation of the F0 values extracted at the five points of the second syllable (carryover effects) and at the five points of the first (anticipatory effects) (0%, 25%, 50%, 75%, 100%).

Finally, in order to test whether High or Low tones are more likely to trigger the carryover effects, we calculated the Pearson's product-moment correlation coefficients. The coefficients reflect the correlation between the offset F0 values on the first tone (fixed to be T1, T2, T3, T4, or T5) and the offset of the second tones following it. The carryover effects may not be sustained throughout for some of the triggers, showing a smaller correlation coefficient. Similarly, in order to test whether High or Low tones are better triggers for anticipatory effects in Nanjing, we tested the correlation between the onset F0 values of the first syllable and those for the onset of the second. All of the statistical analyses were done using the software R. Linear mixed effects models were fitted using the R package "lme4" (R Core Team 2013).

3. RESULTS

3.1 Carryover Effects

The plots of the tonal contours in disyllabic tonal combinations excluding reported sandhi pairs are shown in Figures 2 - 6, where the F0 values extracted at each time point were averaged across speakers. We examined whether the time points are correlated using the partial correlation function (PACF) plot. The PACF plot is a diagnostic tool for examining error dependence. Cryer and Chan (2008) defined PACF as the difference of two prediction errors as follows:

$$\varphi_{kk} = \text{Corr}(Y_t-\beta_1 Y_{t-1}-\beta_2 Y_{t-2}-\ldots-\beta_{k-1} Y_{t-k}, Y_{t-k}-\beta_1 Y_{t-k+1}-\beta_2 Y_{t-k+2}-\ldots-\beta_{k-1} Y_{t-1})$$

where the β's are chosen to minimize the mean squared error of prediction in predicting Y_t based on Y_{t-1}, Y_{t-2}, … Y_{t-k+1}. The sample partial correlation function is defined as follows:

$$\varphi_{kk} = \frac{\rho_k - \sum_{j=1}^{k-1} \varphi_{k-1,j}\rho_{k-j}}{1 - \sum_{j=1}^{k-1} \varphi_{k-1,j}\rho_j}$$

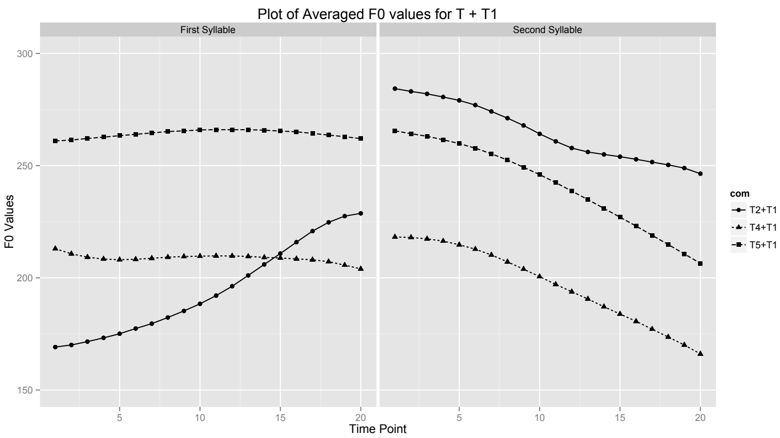

Figure 2. Averaged F0 values of T + T1

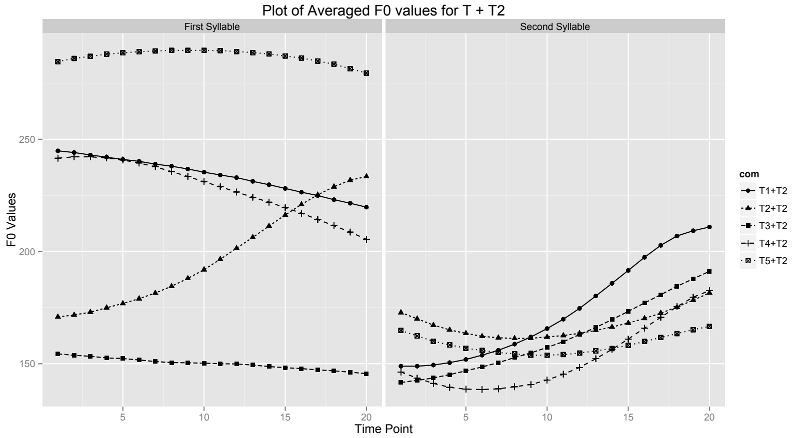

Figure 3. Averaged F0 values of T + T2

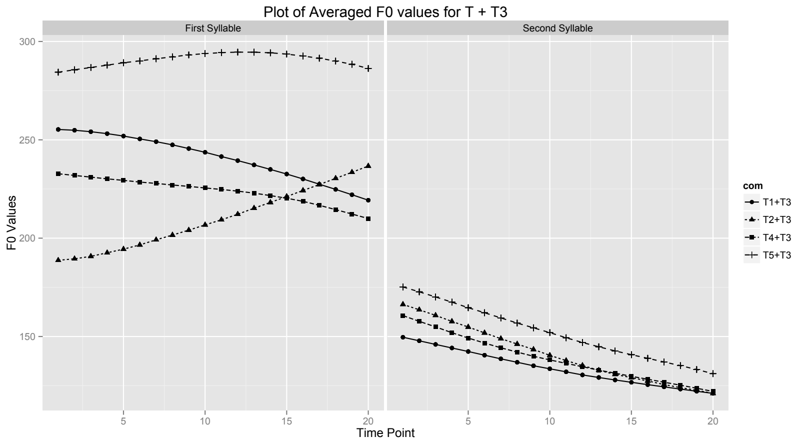

Figure 4. Averaged F0 values of T + T3

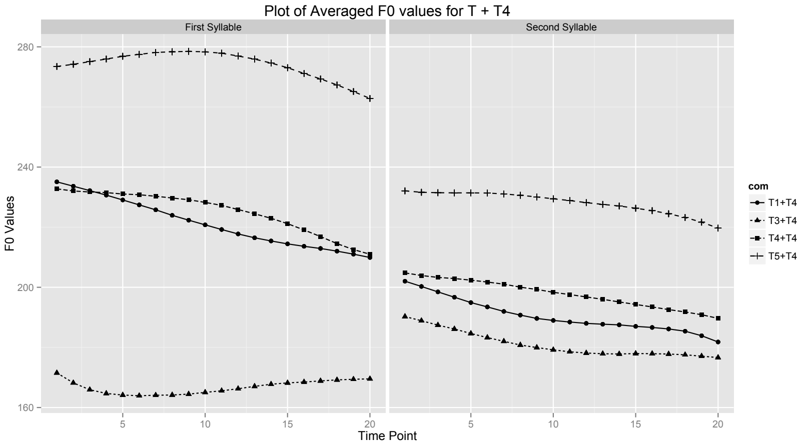

Figure 5. Averaged F0 values of T + T4

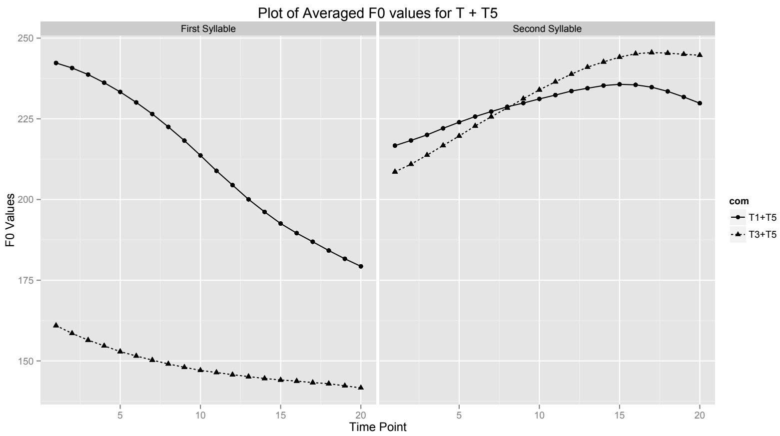

Figure 6. Averaged F0 values of T + T5

Our calculation indicated that any time point was only correlated with the previous one. This is because most series only show correlation at 1 in the PACF plot of Figure 7, and can be modelled as an autoregressive process with order 1 (AR(1)). Therefore, we may treat the time points extracted at 0%, 25%, 50%, 75%, and 100% as independent due to no significant correlation, since each of these time points show 4 time points in between at 5% increments.

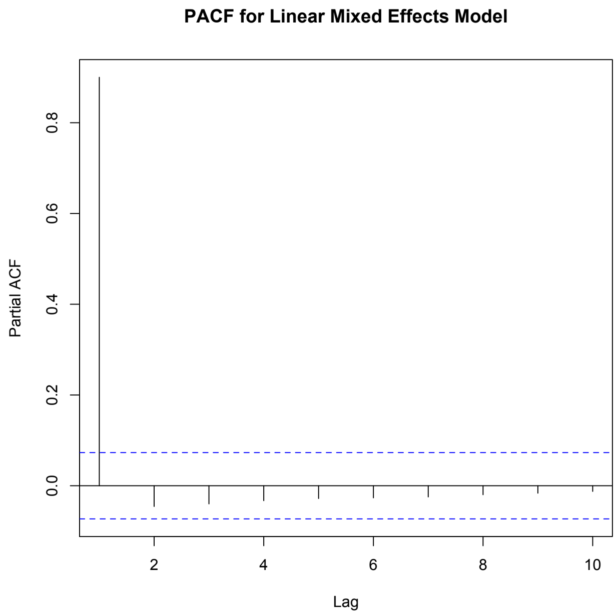

Figure 7. Partial correlation function plot

Figures 2 - 6 provide visual information about the properties of carryover effects. First, the F0 values of the second syllable remain quite different for T1 (31/41), T2 (24/13), and T4 (44). Second, the differences in F0 values on the second syllable shrink toward the end for T3 (22/212/11). Third, the F0 values are similar for T5 (5/55) as the second syllable. Finally, the carryover effects might be assimilatory in that the higher the F0 values of the preceding syllables, the higher the F0 values of the second syllables. We performed statistical analyses to quantify and confirm these properties, and also investigated High and Low tones asymmetry.

Table 3. Comparing the F0 values of second tones for the examination of carryover effects

Combination/ 2^{nd} syllable	Beginning	Point5	Mid	Point 15	End
T + T1	χ^2 (2) = 48.58; $p < 0.001$*	χ^2 (2) = 46.30; $p < 0.001$*	χ^2 (2) = 8.66; $p = 0.01$*	χ^2 (2) = 8.08; $p = 0.02$*	χ^2 (2) = 9.12; $p < 0.001$*
T + T2	χ^2 (4) = 64.96; $p < 0.001$*	χ^2 (4) = 43.20; $p < 0.001$*	χ^2 (4) = 24.30; $p < 0.001$*	χ^2 (4) = 25.61; $p < 0.001$*	χ^2 (4) = 24.52; $p < 0.001$*
T + T3	χ^2 (3) = 13.64; $p = 0.003$*	χ^2 (3) = 12.89; $p = 0.005$*	χ^2 (3) = 10.71; $p = 0.01$*	χ^2 (3) = 6.86; $p = 0.08$	χ^2 (3) = 3.84; $p = 0.28$
T + T4	χ^2 (3) = 14.08; $p = 0.003$*	χ^2 (3) = 18.08; $p < 0.001$*	χ^2 (3) = 22.24; $p < 0.001$*	χ^2 (3) = 23.48; $p < 0.001$*	χ^2 (3) = 86.33; $p < 0.001$*
T + T5	χ^2 (1) = 2.41; $p = 0.12$	χ^2 (1) = 0.63; $p = 0.43$	χ^2 (1) = 0.26; $p = 0.61$	χ^2 (1) = 0.96; $p = 0.33$	χ^2 (1) = 6.42; $p = 0.01$*

T: T1, T2, T3, T4, T5

The results of whether the F0 values differ significantly at the five points (0%, 25%, 50%, 75%, 100%) extracted from the second syllable are presented in Table 3. In all of the combinations, the onsets of the second syllables are significantly different after different offsets of previous tones, suggesting significant carryover effects. These effects are the most prominent at the onset of the second syllable, and shrink toward the end for T3 (22/212/11). The duration for which the carryover effect is sustained does show some differences among the tone types of the second syllable. Specifically, tones starting with higher F0 values are affected for a longer duration by the carryover effect. The effect shows up throughout the second syllable for T1 (31/41) and T4 (44) with statistical significance. Carryover effects of a high tone T5 (5/55) did not show much significance as an exception. However, the duration for which a Low tone target sustains a carryover effect is much shorter. In Nanjing Chinese, T3 (22/212/11) does not show significant carryover effects toward the end, though significant effects are still seen at the midpoint of T3 (22/212/11).

Next, we tested whether the offset of the previous tones has a negative or positive relationship with the F0 values of the second tone. In the linear mixed effects model, we included a fixed effect of the offset F0 values of the first tones in disyllables. The fitted coefficient of this fixed effect indicates that the relationship between the offsets of the first tones and the carryover effects on the second tones. The coefficient reflects the contribution of the F0 values of the offsets of the first tones to the F0 values on the second syllable in the linear mixed effects model. The larger the coefficient is, the stronger the carryover effect. Positive coefficients suggest assimilatory effects and negative coefficients suggest dissimilatory effects. The results show that the coefficients are positive with statistical significance for all five tones at the onset of the second syllable as presented in Table 4, which suggests that the carryover effects in Nanjing Chinese are assimilatory for all of the tones. The offset of the first syllable has the strongest linear relationship with the onset of the second syllable, and the relationship becomes weaker for the mid and end points of the second syllables on T1 (31/41), T2 (24/13), and T3 (22/212/11). Again, tones starting with a higher value (T1 (31/41), T4 (44), and T5 (5/55)) showed a larger coefficient than tones with a lower onset (T2 (24/13) and T3 (22/212/11)), and thus a stronger carryover effect. We also calculated marginal R^2 describing the proportion of the variance explained by the fixed effects, and conditional R^2 describing the proportion of the variance explained by the fixed and random effects (see Nakagawa and Schielzeth 2013). The linear models can explain the response well based on both R^2.

Table 4. The relationship between the offsets of the first tones and the five points of the second tones

	Point 1	**Point 5**	**Point 10**	**Point 15**	**Point 20**
T+T1	Coef = 0.69 χ^2 (1) = 20.42; $p < 0.001$* $R^2_m = 0.82$ $R^2_c = 0.93$	Coef = 0.64 χ^2 (1) = 18.70; $p < 0.001$* $R^2_m = 0.80$ $R^2_c = 0.94$	Coef = 0.57 χ^2 (1) = 17.06; $p < 0.001$* $R^2_m = 0.75$ $R^2_c = 0.94$	Coef = 0.46 χ^2 (1) = 7.51; $p = 0.006$* $R^2_m = 0.63$ $R^2_c = 0.89$	Coef = 0.38 χ^2 (1) =2.29 ; $p = 0.13$ $R^2_m = 0.38$ $R^2_c = 0.64$
T+T2	Coef = 0.13 χ^2 (1) = 10.28; $p = 0.001$* $R^2_m = 0.81$ $R^2_c = 0.95$	Coef = 0.07 χ^2 (1) = 3.41; $p = 0.06$ $R^2_m = 0.82$ $R^2_c = 0.95$	Coef = 0.04 χ^2 (1) = 0.76; $p = 0.38$ $R^2_m = 0.81$ $R^2_c = 0.92$	Coef = 0.09 χ^2 (1) = 0.93; $p = 0.34$ $R^2_m = 0.75$ $R^2_c = 0.88$	Coef = 0.14 χ^2 (1) = 1.12; $p = 0.29$ $R^2_m = 0.69$ $R^2_c = 0.84$

T+T3	Coef = 0.14 χ^2 (1) = 4.86; $p = 0.02$* $R^2_m = 0.61$ $R^2_c = 0.70$	Coef = 0.16 χ^2 (1) = 9.10; $p = 0.003$* $R^2_m = 0.62$ $R^2_c = 0.67$	Coef = 0.14 χ^2 (1) =7.71; $p = 0.005$* $R^2_m = 0.60$ $R^2_c = 0.66$	Coef = 0.12 χ^2 (1) = 6.0; $p = 0.01$* $R^2_m = 0.56$ $R^2_c = 0.65$	Coef = 0.09 χ^2 (1) = 3.66; $p = 0.06$ $R^2_m = 0.50$ $R^2_c = 0.60$
T+T4	Coef = 0.4 χ^2 (1) = 67.49; $p < 0.001$* $R^2_m = 0.85$ $R^2_c = 0.93$	Coef = 0.4 χ^2 (1) = 68.31; $p < 0.001$* $R^2_m = 0.83$ $R^2_c = 0.93$	Coef = 0.33 χ^2 (1) = 46.49; $p < 0.001$* $R^2_m = 0.78$ $R^2_c = 0.92$	Coef = 0.32 χ^2 (1) = 52.93; $p < 0.001$* $R^2_m = 0.76$ $R^2_c = 0.91$	Coef = 0.28 χ^2 (1) = 27.07; $p < 0.001$* $R^2_m = 0.72$ $R^2_c = 0.89$
T+T5	Coef = 0.47 χ^2 (1) = 44.22; $p < 0.001$* $R^2_m = 0.80$ $R^2_c = 0.94$	Coef = 0.49 χ^2 (1) = 45.50; $p < 0.001$* $R^2_m = 0.78$ $R^2_c = 0.95$	Coef = 0.48 χ^2 (1) = 38.50; $p < 0.001$* $R^2_m = 0.76$ $R^2_c = 0.95$	Coef = 0.44 χ^2 (1) = 31.04; $p < 0.001$* $R^2_m = 0.72$ $R^2_c = 0.96$	Coef = 0.38 χ^2 (1) = 16.87; $p < 0.001$* $R^2_m = 0.64$ $R^2_c = 0.93$

T: T1, T2, T3, T4, T5

The results of the maximum, minimum, mean, and standard deviation of the F0 values at the five points of the second syllable (0%, 25%, 50%, 75%, 100%) for each tonal combination are presented in Table 5. The magnitude of the carryover effects differs among the tonal types. Tones with a higher onset such as T1 (31/41), T4 (44), and T5 (5/55) have a larger standard deviation than those with a lower onset T2 (24/13) and T3 (22/212/11), suggesting bigger carryover effects for High tones, which is also attested by the duration of the carryover effects. The above results regarding the duration and magnitude show that High tones are better targets of carryover effects. These results are consistent with previous findings as shown in Table 2.

Table 5. Magnitude of the carryover effects

Point/ Value (Hz)	**0%**	**25%**	**50%**	**75%**	**100%**
Max	T+T1: 486 T+T2: 258 T+T3: 325 T+T4: 352 T+T5: 371	T+T1: 469 T+T2: 235 T+T3: 310 T+T4: 361 T+T5: 384	T+T1: 424 T+T2: 245 T+T3: 299 T+T4: 346 T+T5: 396	T+T1: 361 T+T2: 268 T+T3: 298 T+T4: 340 T+T5: 414	T+T1: 475 T+T2: 315 T+T3: 287 T+T4: 323 T+T5: 428

Min	T+T1: 122	T+T1: 121	T+T1: 113	T+T1: 87	T+T1: 79
	T+T2: 83	T+T2: 84	T+T2: 87	T+T2: 97	T+T2: 103
	T+T3: 77	T+T3: 78	T+T3: 79	T+T3: 78	T+T3: 76
	T+T4: 106	T+T4: 105	T+T4: 101	T+T4: 94	T+T4: 82
	T+T5: 114	T+T5: 121	T+T5: 127	T+T5: 128	T+T5: 104
SD	T+T1: 84.07	T+T1: 82.95	T+T1: 79.05	T+T1: 74.29	T+T1: 76.80
	T+T2: 45.60	T+T2: 42.48	T+T2: 42.98	T+T2: 47.65	T+T2: 52.52
	T+T3: 55.83	T+T3: 50.06	T+T3: 45.11	T+T3: 42.36	T+T3: 40.29
	T+T4: 60.21	T+T4: 58.35	T+T4: 55.90	T+T4: 54.59	T+T4: 54.18
	T+T5: 62.28	T+T5: 64.56	T+T5: 67.15	T+T5: 70.27	T+T5: 70.43
Mean	T+T1: 250.35	T+T1: 245.65	T+T1: 231.45	T+T1: 215.17	T+T1: 198.3
	T+T2: 157.89	T+T2: 153.57	T+T2: 157.22	T+T2: 170.06	T+T2: 185.74
	T+T3: 161.08	T+T3: 151.26	T+T3: 140.26	T+T3: 131.44	T+T3: 123.92
	T+T4: 206.08	T+T4: 201.85	T+T4: 197.39	T+T4: 195.03	T+T4: 190.86
	T+T5: 212.64	T+T5: 221.81	T+T5: 232.57	T+T5: 239.90	T+T5: 237.26

SD: Standard Deviation; T: T1, T2, T3, T4, T5

The results for the Pearson's product-moment correlation coefficients and their significance are presented in Table 6. For High level tones such as T4 (44) and T5 (5/55), the correlation coefficients are generally higher than those for the Low tone T3 (22/212/11), although all of them are statistically significant. The result is consistent with previous findings about the High tones being better triggers in the carryover effects (Xu 1994, 1997; Zhang and Liu 2011).

Table 6. Triggers of the carryover effects

	Pearson's correlation	**Significance**
T1 (offset) vs. T (offset)	0.49	t(130) = 6.40; $p < 0.001$*
T2 (offset) vs. T (offset)	0.41	t(46) = 3.05; $p = 0.004$*
T3 (offset) vs. T (offset)	0.49	t(94) = 5.5; $p < 0.001$*
T4 (offset) vs. T (offset)	0.69	t(106) = 9.69; $p < 0.001$*
T5 (offset) vs. T (offset)	0.48	t(106) = 5.66; $p < 0.001$*

T: T1, T2, T3, T4, T5

From the above analysis, High tones are better triggers and targets of carryover effects. The length of the duration for which the carryover effect is sustained through the High tone targets is longer than for the Low tones except for T5. In addition, High tones exhibit a greater magnitude in the carryover effects than Low tones. High tones also generally demonstrate a stronger correlation with the F0 values of the following syllable, and thus stronger carryover effects than Low tones. In sum, the findings in Nanjing Chinese agree with the general findings for H/L tone asymmetry with respect to carryover effects as described in Table 2, where the High tones are both better triggers and better targets than Low tones.

3.2 Anticipatory Effects

The tonal combinations reported to have undergone tone sandhi were first excluded from examination. Figures 8 - 12 plot the anticipatory effects of all the tonal combinations where the first syllable is fixed to be the same monosyllabic tone (e.g. T1). Some properties of anticipatory effects in Nanjing can be visually inferred from the figures. First, the F0 values of the first syllable show extensive differences. Second, the relationship between the F0 values of the first tone and of the onset of the second tone in each disyllable is not obviously assimilatory or dissimilatory.

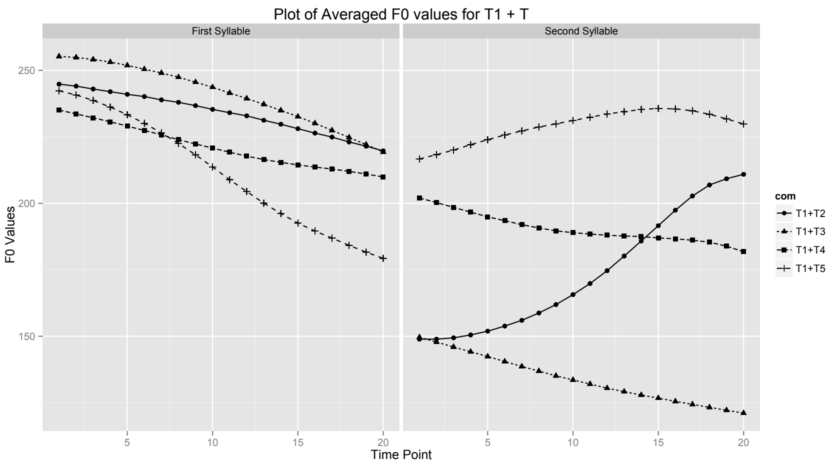

Figure 8 Averaged F0 values of T1 + T

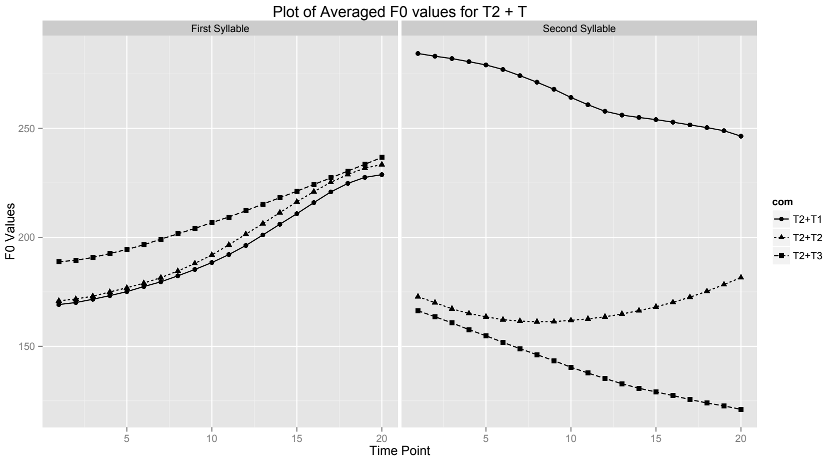

Figure 9 Averaged F0 values of T2 + T

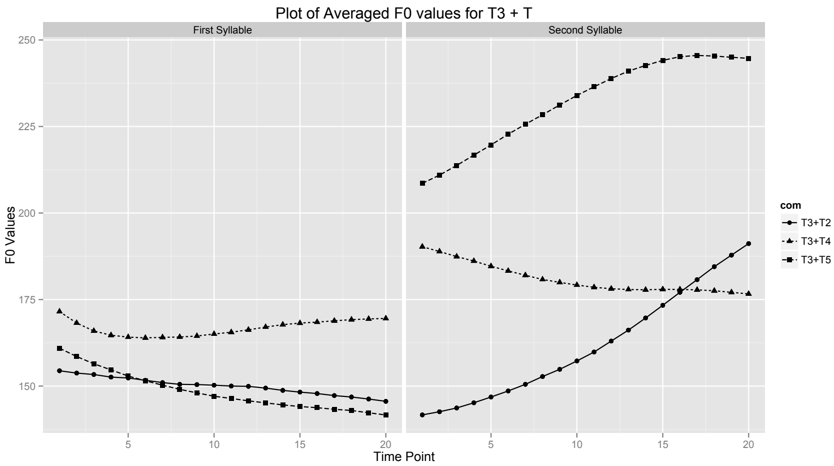

Figure 10 Averaged F0 values of T3 + T

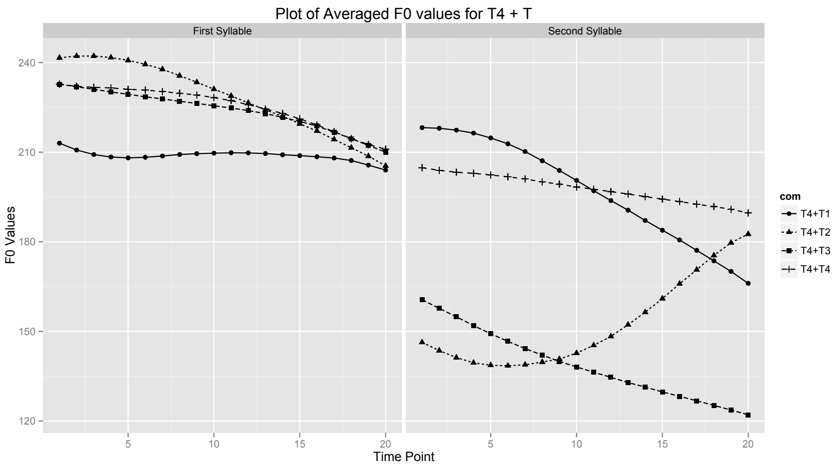

Figure 11 Averaged F0 values of T4 + T

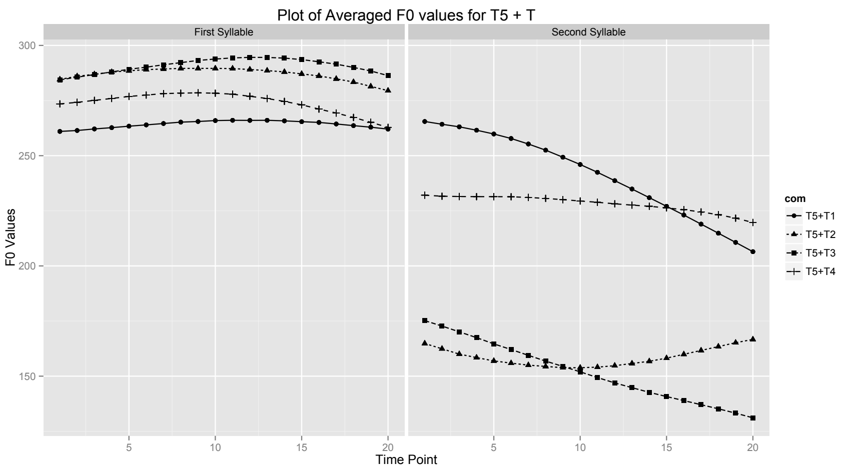

Figure 12 Averaged F0 values of T5 + T

Table 7 presents the results of whether the F0 values of the first tone differ at the five extracted time points (0%, 25%, 50%, 75%, 100%). The anticipatory effects remain significant for T1 (31/41) and T5 (5/55) at most extracted points, but are less salient on other tones. Compared with the carryover effect where 75% of the points tested are significantly different, the anticipatory effect is weaker in terms of the duration that it lasts, where 52% of the points tested show significance. This weaker anticipatory effect in terms of duration is consistent with the findings for the most reported languages as summarized in Table 2. In addition, we 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, which represent the magnitude of the two effects at their strongest points. The magnitude is not significantly different ($t(8) = 0.5$, $p = 0.63$). There is a small difference in the average standard deviation: carryover effects (61.60 Hz) and anticipatory effects (65.91 Hz). This suggests that the two effects are comparable when only magnitude is considered.

Table 7. Comparing the F0 values of first tones for the examination of anticipatory effects

Combination/ 1st syllable	**Beginning**	**Point5**	**Mid**	**Point 15**	**End**
T1 + T	χ^2 (3) = 30.89; p < 0.001*	χ^2 (3) = 40.58; p < 0.001*	χ^2 (3) = 11.23; p = 0.01*	χ^2 (3) = 8.82; p = 0.03*	χ^2 (3) = 7.07; p = 0.07
T2 + T	χ^2 (2) = 6.45; p = 0.04*	χ^2 (2) = 5.72; p = 0.06	χ^2 (2) = 0.93; p = 0.06	χ^2 (2) = 0.12; p = 0.94	χ^2 (2) = 0.08; p = 0.96
T3 + T	χ^2 (2) = 9.00; p = 0.01*	χ^2 (2) = 2.20; p = 0.33	χ^2 (2) = 4.25; p = 0.12	χ^2 (2) = 6.27; p = 0.04*	χ^2 (2) = 35.00; p < 0.001*
T4 + T	χ^2 (3) = 6.08; p = 0.11	χ^2 (3) = 5.88; p = 0.12	χ^2 (3) = 4.55; p = 0.21	χ^2 (3) = 2.51; p = 0.47	χ^2 (3) = 2.00; p = 0.57
T5 + T	χ^2 (3) = 12.71; p = 0.005*	χ^2 (3) = 15.90; p = 0.001*	χ^2 (3) = 18.29; p < 0.001*	χ^2 (3) = 18.81; p < 0.001*	χ^2 (3) = 15.88; p = 0.001*

T: T1, T2, T3, T4, T5

Then we examined four aspects of anticipatory effects. First, the duration for which anticipatory effects are sustained differs among the tone types of the target first syllable. Anticipatory effects on T1 (31/41), T3 (22/212/11), and T5 (5/55) exhibit significance for most of the extracted points, whereas the results for T2 (24/13) and T4 (44) do not show much significance. Tones with Low offsets seem to be more affected by the anticipatory effect than tones with High offsets except for T5 (5/55). Previous studies show that Low tone targets are less affected by anticipatory effects, but our findings are not consistent with such results.

Second, we tested whether the onset of the second tone in each disyllable has a negative or a positive relationship with the F0 values of the first tone. The purpose of this examination is to determine whether anticipatory effects are assimilatory or dissimilatory. In the linear mixed effects model, we included a fixed effect of the second tones' onset F0 values in disyllables. The fitted coefficient of this fixed effect indicates the relationship since it reflects the contribution of the onsets of the second tones to the F0 values of the first syllable. The results of the coefficients and their significance are reported in Table 8. The coefficients were positive for T3 and T4, indicating an assimilatory effect. However, T1 (31/41), T2 (24/13) and T5 (5/55) exhibit negative coefficients, for a dissimilatory effect. Therefore, Nanjing Chinese exhibits both assimilatory and dissimilatory effects in anticipatory coarticulation.

Table 8. The relationship between the onsets of the second tones and the five points of the first tones

	Point 1	**Point 5**	**Point 10**	**Point 15**	**Point 20**
T1 + T	Coef = -0.01 χ^2 (1) = 0.04; $p = 0.85$ $R^2_m = 0.74$ $R^2_c = 0.96$	Coef = -0.02 χ^2 (1) = 0.04; $p = 0.84$ $R^2_m = 0.73$ $R^2_c = 0.96$	Coef = -0.05 χ^2 (1) = 0.30; $p = 0.58$ $R^2_m = 0.71$ $R^2_c = 0.95$	Coef = -0.004 χ^2 (1) = 0.0007; $p = 0.98$ $R^2_m = 0.68$ $R^2_c = 0.91$	Coef = 0.1 χ^2 (1) = 1.05; $p = 0.31$ $R^2_m = 0.65$ $R^2_c = 0.88$
T2 + T	Coef = -0.03 χ^2 (1) = 0.33; $p = 0.57$ $R^2_m = 0.76$ $R^2_c = 0.82$	Coef = -0.02 χ^2 (1) = 0.05; $p = 0.81$ $R^2_m = 0.74$ $R^2_c = 0.86$	Coef = -0.03 χ^2 (1) = 0.05; $p = 0.82$ $R^2_m = 0.67$ $R^2_c = 0.90$	Coef = -0.04 χ^2 (1) = 0.27; $p = 0.61$ $R^2_m = 0.63$ $R^2_c = 0.91$	Coef = -0.05 χ^2 (1) = 0.26; $p = 0.61$ $R^2_m = 0.65$ $R^2_c = 0.88$
T3 + T	Coef = 0.29 χ^2 (1) = 15.52; $p < 0.001$* $R^2_m = 0.79$	Coef = 0.27 χ^2 (1) = 13.91; $p < 0.001$* $R^2_m = 0.73$	Coef = 0.26 χ^2 (1) = 10.36; $p = 0.001$* $R^2_m = 0.66$	Coef = 0.26 χ^2 (1) = 9.26; $p = 0.002$* $R^2_m = 0.58$ $R^2_c = 0.75$	Coef = 0.27 χ^2 (1) = 7.67; $p = 0.006$* $R^2_m = 0.58$ $R^2_c = 0.72$

	$R^2_c = 0.84$	$R^2_c = 0.81$	$R^2_c = 0.78$		
T4 + T	Coef = 0.13 χ^2 (1) = 1.98; $p = 0.16$ $R^2_m = 0.77$ $R^2_c = 0.93$	Coef = 0.14 χ^2 (1) = 2.21; $p = 0.14$ $R^2_m = 0.75$ $R^2_c = 0.93$	Coef = 0.15 χ^2 (1) = 3.15; $p = 0.08$ $R^2_m = 0.77$ $R^2_c = 0.94$	Coef = 0.22 χ^2 (1) = 6.52; $p = 0.01$* $R^2_m = 0.79$ $R^2_c = 0.93$	Coef = 0.38 χ^2 (1) = 12.83; $p < 0.001$* $R^2_m = 0.80$ $R^2_c = 0.91$
T5 + T	Coef = -0.11 χ^2 (1) = 3.00; $p = 0.08$ $R^2_m = 0.70$ $R^2_c = 0.87$	Coef = -0.13 χ^2 (1) = 3.05; $p = 0.08$ $R^2_m = 0.69$ $R^2_c = 0.88$	Coef = -0.15 χ^2 (1) = 3.05; $p = 0.08$ $R^2_m = 0.69$ $R^2_c = 0.89$	Coef = -0.17 χ^2 (1) = 3.32; $p = 0.07$ $R^2_m = 0.68$ $R^2_c = 0.89$	Coef = -0.15 χ^2 (1) = 2.71; $p = 0.10$ $R^2_m = 0.67$ $R^2_c = 0.88$
T: T1, T2, T3, T4, T5					

Third, we examined the magnitude of this effect for each tonal combination, by presenting the maximum, minimum, mean and standard deviation extracted at five different points of the first syllable (0%, 25%, 50%, 75%, 100%) reported in Table 9. Across the tone types, we found differences of magnitude in the anticipatory effects. When the first tone has a High tone such as T5 (5/55), the standard deviation is much higher than for 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. However, T1 (31/41) with a lower offset shows more variation than T2 (24/13) and even T4 (44). Therefore, the magnitude of the anticipatory effects does not consistently show the H/L asymmetry attested in other studies, at least for targets.

Table 9. Magnitude of the anticipatory effects

Point/ Value	**0%**	**25%**	**50%**	**75%**	**100%**
Max	T1+T: 464 T2+T: 303 T3+T: 288 T4+T: 386 T5+T: 475	T1+T: 465 T2+T: 298 T3+T: 290 T4+T: 384 T5+T: 472	T1+T: 457 T2+T: 308 T3+T: 289 T4+T: 365 T5+T: 473	T1+T: 433 T2+T: 370 T3+T: 288 T4+T: 350 T5+T: 481	T1+T: 407 T2+T: 432 T3+T: 283 T4+T: 372 T5+T: 456

Min	T1+T: 127	T1+T: 121	T1+T: 113	T1+T: 106	T1+T: 95
	T2+T: 91	T2+T: 94	T2+T: 98	T2+T: 109	T2+T: 122
	T3+T: 87	T3+T: 86	T3+T: 84	T3+T: 82	T3+T: 80
	T4+T: 120	T4+T: 115	T4+T: 116	T4+T: 115	T4+T: 114
	T5+T: 167	T5+T: 170	T5+T: 174	T5+T: 173	T5+T: 155
SD	T1+T: 81.36	T1+T: 80.41	T1+T: 76.34	T1+T: 72.70	T1+T: 70.91
	T2+T: 48.65	T2+T: 49.15	T2+T: 53.07	T2+T: 61.94	T2+T: 73.24
	T3+T: 51.06	T3+T: 49.32	T3+T: 48.12	T3+T: 47.45	T3+T: 45.56
	T4+T: 64.86	T4+T: 65.74	T4+T: 64.02	T4+T: 61.86	T4+T: 60.62
	T5+T: 71.63	T5+T: 73.91	T5+T: 76.73	T5+T: 79.20	T5+T: 79.22
Mean	T1+T: 245.28	T1+T: 239.62	T1+T: 228.48	T1+T: 216.32	T1+T: 205.88
	T2+T: 174.92	T2+T: 180.79	T2+T: 194.75	T2+T: 216.15	T2+T: 233.04
	T3+T: 165.42	T3+T: 158.45	T3+T: 156.45	T3+T: 156.66	T3+T: 156.08
	T4+T: 229.34	T4+T: 226.29	T4+T: 223.22	T4+T: 217.85	T4+T: 208.37
	T5+T: 275.57	T5+T: 279.27	T5+T: 281.99	T5+T: 279.76	T5+T: 272.33

SD: Standard Deviation; T: T1, T2, T3, T4, T5

Finally, to examine the trigger effects by tones, the Pearson's correlation was calculated. The Pearson's correlation coefficients and their statistical significance are presented in Table 10. All of the correlation coefficients were found to be significant, but a stronger correlation is found for the High level tones T4 (44) and T5 (5/55) show a stronger correlation than the Low tone T3 (22/212/11) as well as the falling and rising T1 (31/41) and T2 (24/13). These results indicate that High tones are better triggers of the anticipatory effect in Nanjing Chinese.

Table 10. Triggers of the anticipatory effects

	Pearson's correlation	**Significance**
T (onset) vs. T1 (onset)	0.75	t(58) = 8.6; $p < 0.001$*
T (onset) vs. T2 (onset)	0.61	t(70) = 6.48; $p < 0.001$*
T (onset) vs. T3 (onset)	0.69	t(142) = 11.27; $p < 0.001$*
T (onset) vs. T4 (onset)	0.89	t(142) = 22.85; $p < 0.001$*
T (onset) vs. T5 (onset)	0.79	t(70) = 10.92; $p < 0.001$*

T: T1, T2, T3, T4, T5

In sum, the anticipatory effect is slightly weaker than the carryover effect in terms of duration, but approximately equal in magnitude. These findings are consistent with those for Malaysian Hokkien (Chang and Hsieh 2012), but not with those for other tone languages reported in the literature. From the visual interpretation and the statistical analysis, we obtained the following properties of the anticipatory effect. First, Low tones and tones with low offsets are subject to anticipatory effects for longer durations than High tones except for T5 (5/55). These results are not consistent with the results for most languages, where High tones show more prominent anticipatory effects (Wong 2006; Zhang and Liu 2011). Second, when the magnitude of the effect is examined, there are no obvious patterns of the H/L asymmetry as proposed in the literature. Third, High tones are better triggers of the anticipatory effects, which conflicts with the findings for Standard Chinese, Taiwanese, Thai, and Tianjin Chinese summarized in Table 2. Finally, Nanjing Chinese exhibits both assimilatory and dissimilatory anticipatory effects, a language-specific property.

4. DISCUSSION

In Section 1.2, we present a typology of tonal coarticulation properties based on findings in the literature. The typology includes a comparison of the carryover and anticipatory effects in terms of magnitude and duration. Most languages exhibit the trend that the carryover effect is greater than the anticipatory effect. However, this trend is not found for Malaysian Hokkein (Chang and Hsieh 2012) or for Nanjing Chinese in terms of magnitude. The two effects show a similar magnitude, though the carryover effect exhibits longer duration than the anticipatory effect in both languages.

In order to examine the duration of the carryover effects, we fitted linear mixed effects models. Unsurprisingly, the carryover effect is most prominent at the onset of the second syllable and shrinks toward the end for some tones. Tones starting with a higher F0 value display a longer carryover effect, and are thus better targets for the carryover effect in general. These findings agree with those for most of the languages reported in the literature, except for Cantonese that shows the opposite trend. The analysis of the magnitude, where carryover effects are greater for High tones, also confirms the trend that High tones are better targets for carryover. High tones are also better triggers of the carryover effect because they generally show a stronger correlation with the tone of the following syllable, and thus they generate stronger carryover effects than

Low tones. This fact is also in agreement with the findings for most other languages, except for Malaysian Hokkein, where no consistent patterns are observed. Furthermore, the carryover effects are assimilatory, except for one tone pair in Tianjin Chinese and some of the tonal pairs in Malaysian Hokkein.

Similar analyses were made to examine anticipatory effects in Tianjin Chinese. 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, which is not consistent with most of the languages reported in the literature. When magnitude is examined, no consistent results are found concerning the H/L tone asymmetry. The strength of the anticipatory effects varies for each individual tone without an obvious H/L tone asymmetry pattern. In Nanjing Chinese, High tones are better triggers of the anticipatory effects than are Low tones, which finding is also not consistent with that for most of the languages in the literature either. Therefore, the inconsistent results found in Malaysian Hokkein and Nanjing Chinese challenge the universal nature of the H/L asymmetry of carryover and anticipatory effects, which motivates further studies of other languages in the future.

Furthermore, our findings on the properties of tonal coarticulation contrary to previous generalizations call for further studies to enhance our understanding of the universality of tonal coarticulation, and to create a better typology. Specifically, based on the results in this study and other recent studies, we list some new findings. First, the magnitude of carryover and anticipatory effects may be comparable in some languages, whereas it is not the case that carryover effects are always stronger than anticipatory effects, as in Nanjing Chinese and Malaysian Hokkein. Second, the carryover effects can be dissimilatory for certain tonal pairs, as in Tianjin Chinese and Malaysian Hokkein. Third, the anticipatory effects can be totally assimilatory for every tonal pair as in Vietnamese, or assimilatory for only some pairs as in Standard Chinese, Taiwanese, Nanjing Chinese, and Malaysian Hokkein, or dissimilatory for all tonal pairs as in Thai, Cantonese, Yoruba, and Tianjin Chinese. Fourth, there may not be consistent results for the H/L asymmetry, as in Nanjing Chinese and Malaysian Hokkein. Based on these findings, the typology can be updated as in Table 11.

Table 11. An updated typology of tonal coarticulation properties

Properties		**Languages**
Magnitude	P > R	Mandarin; Taiwanese; Vietnamese; Thai; Cantonese; Tianjin Chinese
	P ≈ R	Malaysian Hokkein; Nanjing Chinese
Assi. or dissi.	P: assi.; R: dissi.	Thai; Cantonese; Yoruba
	P: assi; R: assi/dissi.	Mandarin; Taiwanese; Nanjing Chinese
	P: assi; R: assi	Vietnamese;
	P: assi/dissi; R: dissi.	Tianjin Chinese
	P: assi/dissi; R: assi/dissi	Malaysian Hokkein
H/L asymmetry	P trigger: H > L	Mandarin; Vietnamese; Tianjin Chinese; Nanjing Chinese
	P trigger: No consistent results	Malaysian Hokkein
	P target: H > L	Mandarin; Tianjin Chinese; Nanjing Chinese
	P target: L > H	Cantonese
	R trigger: L > H	Mandarin; Taiwanese; Thai; Tianjin Chinese
	R trigger: H > L	Nanjing Chinese
	R trigger: No consistent results	Malaysian Hokkein
	R target: H > L	Cantonese; Tianjin Chinese
	R target: No consistent results	Nanjing Chinese

P = progressive; R = regressive; assi = assimilatory; dissi = dissmilatory; assn = assimilation; dissn = dissimilation

5. CONCLUSIONS

In this study, we explored the properties of anticipatory and carryover effects in Nanjing Chinese by visual interpretation and statistical analyses. Specifically, the carryover and anticipatory effects show similar magnitudes rather than a bias toward stronger carryover effects. The magnitude of the anticipatory effects does not consistently show H/L asymmetry. The results reported above, together with recent studies, lead us to update the current typology of tonal coarticulation properties, and challenge previous understandings about the characteristics of the two effects.

REFERENCES

Aston, John AD, Jeng-Min Chiou, and Jonathan P. Evans. 2010. Linguistic pitch analysis using functional principal component mixed effect models. *Journal of the Royal Statistical Society: Series C (Applied Statistics)* 59(2): 297-317.

Boersma, Paul and David Weenink. 2013. Praat: doing phonetics by computer [Computer program]. Version 5.3.51, retrieved 2 June 2013 from http://www.praat.org

Box, George EP, and David A. Pierce. 1970. Distribution of Residual Autocorrelations in Autoregressive-Integrated Moving Average Time Series Models. *Journal of the American Statistical Association* 65: 1509–1526.

Brunelle, Marc. 2003. Tone coarticulation in Northern Vietnamese. In *Proceedings of the 15th International Congress of Phonetic Sciences*, Spain, pp. 2673–2676.

Brunelle, Marc. 2009. Northern and Southern Vietnamese Tone Coarticulation: A Comparative Case Study. *Journal of Southeast Asian Linguistics* 1: 49-62.

Chang, Yueh-chin, and Feng-fan Hsieh. 2012. Tonal coarticulation in Malaysian Hokkien: A typological anomaly? *The Linguistic Review* 29: 37-73.

Chao, Yuen Ren. 1930. A system of tone letters. *Le maitre phonetique* 45: 24-27.

Chao, Yuen Ren. 1948. *Mandarin Primer*. Cambridge: Harvard University Press.

Chao, Yuen Ren. 1956. Tone, intonation, singsong, chanting, recitative, tonal composition, and atonal composition in Chinese. In *For Roman Jacobson*, eds. by M. Halle, pp. 52-59. Mouton: The Hague.

Chao, Yuen Ren. 1968. *A Grammar of Spoken Chinese*. Berkeley, California: University of California Press.

Chappell, Hilary. 2002. The universal syntax of semantic primes in Mandarin Chinese. In *Meaning and Universal Grammar: Theory and Empirical Findings 1*, eds. Cliff Goddard, Anna Wierzbickam, pp. 243-322. John Benjamins Publishing Company

Chen, Matthew Y. 2000. *Tone sandhi patterns across Chinese dialects*. Cambridge, UK: Cambridge University Press.

Chen, Si, and Caroline Wiltshire. 2013. Tone Realization in Younger vs. Older speakers of Nanjing Dialect. In *Increased Empiricism: Recent Advances in Chinese Linguistics,* ed. by Jing-Schmidt Zhuo, pp. 147 – 170. Amsterdam and Philadelphia: Benjamins.

Chen, Si, Caroline Wiltshire, and Bin Li. to appear. Statistical Modeling of Mandarin Tone Sandhi: Neutralization of Underlying Pitch Targets. In *Proceedings of ICCLL 2017: International Conference on Chinese Language and Linguistics*, London, United Kingdom.

Cheng, Chin-Chuan. 1968. English stresses and Chinese tones in Chinese sentences. *Phonetica* 18(2): 77-88.

Cryer, Jonathan D. and Kung-Sik Chan. 2008. *Time series analysis: with applications in R*. Springer.

Flemming, Edward. 2011. La grammaire de la coarticulation (The grammar of coarticulation). In *La Coarticulation: Des indices à la Représentation*, eds. by Mohamed Embarki and Christelle Dodane, pp. 189-211. Paris: L'Harmattan.

Gandour, Jack, Siripong Potisuk, Sumalee Dechongkit, and Suvit Ponglorpisit. 1992a. Tonal coarticulation in Thai disyllabic utterances: a preliminary study. *Linguistics of the Tibeto-Burman Area* 15: 93-110.
Gandour, Jack, Siripong Potisuk, Sumalee Dechongkit, and Suvit Ponglorpisit. 1992b. Anticipatory tonal coarticulation in Thai noun compounds. *Linguistics of the Tibeto-Burman Area* 15: 111-124.
Gandour, Jack, Siripong Potisuk, and Sumalee Dechongkit. 1994. Tonal coarticulation in Thai. *Journal of Phonetics 22*: 477-492.
Jangjamras, Jirapat. 2012. *Perception and production of English lexical stress by Thai speakers*. PhD. dissertation. University of Florida.
Laniran, Yetunde O., and George N. Clements. 2003. Downstep and high raising: interacting factors in Yoruba tone production. *Journal of Phonetics* 31: 203-250.
Li, Qian, and Yiya Chen. 2016. An acoustic study of contextual tonal variation in Tianjin Mandarin. *Journal of Phonetics* 54: 123 – 150.
Li, Xingjian, and Sixun Liu. 1985. Tianjin fangyan de liandu biandiao (Tone sandhi in the Tianjin dialect). *Zhongguo Yuwen* 1: 76-80.
Lin, Hwei-Bing. 1988. *Contextual stability of Taiwanese tones*. Storrs: University of Connecticut dissertation.
Liu, Danqing. 1995. *Nanjing Dialect Dictionary*. Jiangsu: Jiangsu Education Publisher.
Liu, Danqing. 1997. *Nanjing Dialect Phonetic Profile*. Shanghai: Shanghai Education Publisher.
Matthews, Stephen, and Virginia Yip. 1994. *Cantonese: A comprehensive grammar*. Routledge.
Myers, Scott. 2003. F0 timing in Kinyarwanda. *Phonetica* 60: 71-97
Nakagawa, Shinichi, and Holger Schielzeth. 2013. A general and simple method for obtaining R2 from generalized linear mixed-effects models. *Methods in Ecology and Evolution* 4: 133–142.
Peng, Shu-Hui. 1997. Production and perception of Taiwanese tones in different tonal and prosodic contexts. *Journal of Phonetics* 25: 371–400.
Potisuk, Siripong, Jackson Gandour, and Mary P. Harper. 1997. Contextual variations in trisyllabic sequences of Thai Tones. *Phonetica* 54: 22-42.
R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/
Rose, Phil. 1987. Considerations in the normalization of the fundamental frequency of linguistic tone. *Speech communication* 6: 343-52.
Shen, Xiaonan Susan. 1990. Tonal coarticulation in Mandarin. *Journal of Phonetics*, 18: 281-295.
Shen, Xiaonan Susan. 1992. On tone sandhi and tonal coarticulation. *Acta Linguistica Hafniensia*: *25*(1): 83 – 94.
Shi, Feng. 1986. Tianjin fangyan shuangzizu shengdiao fenxi (Analysis of disyllabic tones in Tianjin dialect). *Yuyan Yanjiu* 10: 77–90.

Song, Yidan. 2006. *Nanjing Fangyan Shengdiao Shiyan Yanjiu*. (The acoustic study of tones in Nanjing dialect). Nanjing: Nanjing Normal University Master's thesis.

Sun, Huaxian. 2003. Nanjing Fangyan Shengdiao de Ruogan Wenti. (A discussion on the tones of Nanjing dialect). *Journal of Nanjing Xiaozhuang College* 1: *34 - 40*.

Wong, Ying Wai. 2006. Contextual tonal variations and pitch targets in Cantonese. In *Proceedings of Speech Prosody*, Germany, pp. 317-320

Xu, Chi, Maosong Liu, Cheng Zhang, Shuqing An, Wen Yu, and Jing M. Chen. 2007. The spatiotemporal dynamics of rapid urban growth in the Nanjing metropolitan region of China. *Landscape Ecology,* 22(6): 925 - 937.

Xu, Yi. 1997. Contextual tonal variations in Mandarin. *Journal of Phonetics* 25: 61-83

Zhang, Jie. and Yuwen Lai. 2010. Testing the role of phonetic knowledge in Mandarin tone sandhi. *Phonology* 27(1): 153-201.

Zhang, Jie. and Jiang Liu. 2011. Tone sandhi and tonal coarticulation in Tianjin Chinese. *Phonetica* 68(3): 161-191.

Zhu, Xiaonong Sean. 1999. *Shanghai Tonetics*. Canberra: Australian National University dissertation.

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APPENDIX

Disyllabic word list

First↓ Second →	T1	T2	T3	T4	T5
T1	T1 T1 豬肝 [tʂu kɑŋ] 司機 [sɿ tɕi] 相思 [ɕiɑŋ sɿ]	T1 T2 分離 [fən li]	T1 T3 觀點 [kuɑn tien] 思想 [sɿ ɕiɑŋ] 生理 [sən li] 收禮 [səɯ li]	T1 T4 關店 [kuɑn tien] 相似 [ɕiɑŋ sɿ] 多謝 [to sie]	T1 T5 公立 [koŋ li] 收集 [səɯ tɕi] 高級 [kɔo tɕi]
T2	T2 T1 流星 [liəɯ sin]	T2 T2 煩神 [fɑn sən] 流行 [liəɯ ɕin]	T2 T3 民主 [min tʂu]	T2 T4 N.A.	T2 T5 民族 [min tsu]
T3	T3 T1 手機 [səɯ tɕi]	T3 T2 幾年 [tɕi lien]	T3 T3 打賭 [tɑ tu] 保險 [pɔo ɕien] 手裡 [səɯ li] 俘虜 [fu lu]	T3 T4 主幹 [tʂu kɑŋ] 死相 [sɿ ɕiɑŋ] 打架 [tɑ ɕiɑ] 打鬧 [tɑ lɔo]	T3 T5 省力 [sən li] 組織 [zu tʂʅ] 簡歷 [tɕien li]
T4	T4 T1 大家 [tɑ ɕiɑ] 上街 [sɑŋ tɕie]	T4 T2 路盲 [lu mɑŋ]	T4 T3 治理 [tʂʅ li] 大腦 [tɑ lɔo] 禁賭 [tɕin tu] 敬禮 [tɕin li]	T4 T4 四季 [sɿ tɕi] 勝利 [sən li]	T4 T5 智力 [tʂʅ li] 祝福 [tʂu fu] 附錄 [fu lu] 奮力 [fən li] 禁毒 [tɕin tu]

T5	T5 T1 鐳射 [tɕi kuɑŋ] 讀書 [tu ʂu]	T5 T2 力行 [li ɕin]	T5 T3 發表 [fɑ piɔo] 毒死 [tu sɿ] 極小 [tɕi ɕiɔo]	T5 T4 出事 [tsu ʂʅ] 局部 [tɕy pu] 國際 [ko tɕi]	T5 T5 國籍 [ko tɕi] 屋脊 [u tɕi] 格局 [kə tɕy] 蠟燭 [lɑ tʂu]

聲調協同發音特性的類型學更新

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本研究考察了南京方言的聲調協同發音現象，並與其他語言進行了比較。儘管許多語言表現出類似的特徵，但近來對一些語言的考察結果與先前研究的結論並不一致。本研究採用了線性混合效應模型，並計算了皮爾遜相關係數。南京方言在這兩種效應中表現出類似的幅度，與先前結論不符。此外，其高低音不對稱的特性也與其他語言不一致。 據此我們提出了聲調協同發音特性的類型學更新。

關鍵字：聲調協同發音、滯後效應、預期效應、南京方言、類型學