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研究生劉季蓉

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碩士論文

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客家話大埔音聲調之聲學研究

Tonal Representations and Coarticulation in Ta-pu Hakka

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致謝

五年了！五年可以讓一個人成就什麼呢？

結婚生子，同時兼顧上班與學業，中間休學了一年——最後在老公均凱、家人及我的指導教授江文瑜博士的支持下，完成了碩士學位。這個碩士學位，說真的，不是我一個人的能力所能完成的。親愛的媽咪與爹地，因為有你們無怨無悔地幫我照顧小孩，我才能在第一年留職停薪唸書的時候，儘量多修一些課，以便之後較有時間能夠一邊唸書，同時又回到工作崗位上；體貼的婆婆，總是能體會我身兼三職的辛苦，從不計較我是個沒做什麼家事的媳婦；最勞苦功高的是我親愛的老公，總是在下班回來之後，即使拖著一身疲憊，仍包辦所有的家事，在假日，也儘量陪兩個小孩玩，為的就是能讓我專心寫完論文。這篇論文的完成，真的是我所有家人共同幫我完成的一項任務。

回想六年前，剛踏進語言所的第一天，是帶著一貫道郭明義點傳師所幫忙完成的一篇小論文參加口試，非常感恩當時的口試的教授們（蘇以文教授、江文瑜教授、以及張顯達教授）不因我拙劣的小論文而對我失去信心。這六年來，雖然在語言所的求學過程是斷斷續續的，然而，所有台大語言所的教授群對我的教導與訓練，讓我不僅對語言學的各種風貌有更深一層的認識，更讓自已在思考能力，邏輯分析及研究方法上，有很大的進步。其中，尤其要感謝的是我的指導教授江文瑜博士，老師知道我身兼多職，了解我能跟老師討論的時間有限，但老師總是能在最短的時間內，給我最大的幫助，讓我從論文的構想，到語音實驗設計及統計方法各方面都能更為完備。寫論文的辛苦，加上帶小孩，上班的壓力，每每讓我喘不過氣來，但只要想到老師的一句話：「季蓉，加油！撐下去！快完成了！」總讓我在每天晚上九點哄小孩入睡後，又強打起精神，繼續寫下去。老師對我的體諒、支持、與鼓勵絕對是這本論文的最大推手，讓我想跟所有台大語言所的學弟妹說：「沒有江老師，就沒有我的碩士學位！」此外，更要感謝學位考試當天台大馮怡蓁教授及交大潘荷仙教授對我的論文所提出的指正與建議，讓我能將論文中的不足及缺點做最大的修正。

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們看書，玩玩具。但還是要感謝你們願意早一點上床睡覺，讓我有多一點時間寫論文，尤其是珮榆，總是在妹妹睡著後，願意獨自一人聽著音樂、或是故事而入睡；還要感謝我的四個妹妹們，有你們的鼓勵，有你們在空閒的時候幫忙我照顧小孩，讓我有更多的時間做研究。更感謝我親愛的爸媽，姑姑，在我出國發表論文的期間，幫我照顧兩個小天使。尤其是我的爸媽，沒有你們多年來的栽培，我不可能走到這一步。

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Abstract

This present study aims (1) to investigate the correlation of phonological representations and phonetic realizations of Ta-pu Hakka tones, and (2) to explore the tonal coarticulation in different kinds of contexts.

There are two major Hakka sub-dialects spoken in Taiwan, the Hai-lu and the Suu-hsien systems. Another sub-dialect, Ta-pu Hakka, is spoken mainly in some townships in central Taiwan by about 60,000 people. Different sub-dialects of Hakka have their own tonal systems that have been described in detail in previous literature. However, most of the tonal representations used in the literature with regard to tones were based on auditive perception and phonological description. As a result, those phonological tonal representations were more impressionistic.

This study first investigated the correlation between phonological representations and phonetic realizations of the Ta-pu Hakka tones by taking acoustic and statistical approaches. Six informants, including three males and three females, were recruited in this study. Two sets of inventories were adopted as the test stimuli: the first was a set of monosyllabic words, and the other was a set of disyllabic words. The monosyllabic words were used to verify the citation tones, while the disyllabic words were used to verify the sandhi tones. Meanwhile, the tonal representations in different prosodic positions, i.e., in word-initial (WI) and in word-final (WF) positions were also investigated.

The second research question in this study was to explore tonal coarticulation in disyllabic words in Ta-pu Hakka. Tonal coarticulation refers to tonal variations in consecutive speech, which has been a great concern to many phoneticians (Xu, 1994, 1997, 1999, 2002, 2004; Gandour et al., 1994; Peng, 1997; Shen, 1990). In this study, we investigated tonal variations in different prosodic positions, tonal contexts, and in a context with different neighboring tones. Target Approximation model (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001) was used to help explain the tonal variations found in this language.

To answer the above two research questions, we measured the average pitch height (F0) of the beginning point (BP), the ending point (EP), the maximum pitch (F0_Peak), the minimum pitch (F0_valley), and the average pitch of the syllable (Mean_F0). Besides, we also calculated the mean slope and the mean duration of the whole syllable. For ***Yang-Ping*** tone, the F0 valley alignment was calculated. As for falling tones and checked tones, the F0 peak alignment was calculated instead.

In investigating tonal representations, we adopted Fon and Chiang's (1999) postulated formulae and Shi's (1990) logarithmic function. In the first section with

regard to verifying the tonal representations in Ta-pu Hakka, the revised T-scales (5-scaled tonal system) of the seven citation tones were suggested as follows: ***Yin-Ping*** as [33], ***Yang-Ping*** as [313], ***Shang*** as [31], ***Chü*** as [53], ***Yin-Ju*** as [3], ***Yang-Ju*** as [4], and ***Supra-Yin-Ping*** as [34], based on the data from monosyllabic words.

As for the tones in disyllabic words, the T-scales showed great incongruence between the results obtained via the two calculation methods. The results suggested that tonal representations in disyllabic words should not be considered as the norms of tonal representations. As for the three sandhi tones (ST), we found that the revised T-scales via Shi's function were more appropriate to show their phonetic realizations. The three sandhi tones were suggested as ST-***Yin-Ping*** as [324], ST-***Yang-Ping*** as [323], and ST-***Chü*** as [44], respectively. However, the revised T-scales in fact represented the phonetic realizations of the sandhi tones under the influence of tonal coarticulation, so we would still adopt the original T-scales, ST-***Yin-Ping*** as [35], ST-***Yang-Ping*** as [33], and ST-***Chü*** as [55], when sandhi tones were involved in investigating tonal coarticulation effect.

The phonetic realizations of tones in Ta-pu Hakka showed that the seven citation tones included one level tone, two falling tones, two checked tones, one rising tone, and one concave tone. The tones in this language could be paired off, one belonged to the lower register, whereas the other belonged to the higher register. Note that the T-scales of the two checked tones were very close to each other. The statistical results of comparing means of the measured parameters in the two checked tones indicated that not only the pitch height but also the falling slope served as the criterion of distinguishing one from the other, within which the lower checked tone, ***Yin-Ju*** [3], had a steeper falling F0 slope.

As for tonal coarticulation, we explored the tonal variations from different aspects. First we investigated the tonal variations of tones according to their position in disyllabic words, namely in WI and WF positions. Afterward, Xu's (1994) classification of different tonal combinations into a compatible or a conflicting context was examined and modified based on the tonal combinations in Ta-pu Hakka. We proposed a third type of tonal context, which was termed as a ***contour compatible context***, referring to a context where a rising tone followed by a falling tone, or a falling tone followed by a rising tone. Then the influence of adjacent tones on their preceding or following tone was compared and discussed.

The results of tonal coarticulation in Ta-pu Hakka were summarized as follows. First, in regard with the position effect, final-lengthening was found in all the non-falling tones and the ***Yang-Ju*** [4]. However, the duration of ***Yin-Ju*** [3] and ***Shang*** [31] was longer in WI rather than in WF. Furthermore, the mean F0 slope of these two tones was steeper in WF position, indicating an abrupt fall at the end of the utterance.

As for ***Supra-Yin-Ping*** [34], however, the mean slope was steeper when it was in SI than in SF. The most interesting finding was that the F0 valley alignment of ***Yang-Ping*** [313] was closer to the onset in WI, and it became closer to the middle of a syllable when in WF.

With regard to the tonal variations in a compatible or conflicting context, we found that ***Shang*** [31] showed a steeper slope in a contour compatible context than in a conflicting context. The result also suggested that a contour compatible context was very similar to a compatible context. As for ***Supra-Yin-Ping*** [34], the slope was even steeper in a contour compatible context than in a compatible context.

As for the results of the influence of adjacent tones on each other, carryover assimilation effect was found in ***Yin-Ping*** [33], ***Yang-Ping*** [313], ***Supra-Yin-Ping*** [34], ***Chü*** [53] and ***Yang-Ju*** [4]. Anticipatory assimilation was found in ***Shang*** [31], ***Chü*** [53] and ***Yin-Ju*** [3]. For ***Yang-Ju*** [4], anticipatory effect was also found, but the influence of its following tones on its tonal variations showed both assimilation and dissimilation effect. Furthermore, we also found a positive correlation between the offset F0 in syllable 1 (WI) and the onset F0 in syllable 2 (WF).

Furthermore, the tonal variations found in Ta-pu Hakka could be explored via Xu's Target Approximation model. Both anticipatory assimilation and carryover assimilation phenomena supported Xu's claim that "when two pitch targets occur next to each other, if the offset of the first one is different from the onset of the second one, the second one will appear as if it has been assimilated or partially assimilated to the second" (Xu and Wang 2001, p. 329). As for the anticipatory dissimilation, the effect could be found in ***Yin-Ping*** sandhi rule ([33] turning [35]) and ***Yang-Ping*** sandhi rule ([313] turning [33]). On the other hand, the anticipatory assimilation could also be seen in ***Chü*** sandhi rule ([53] turning [43]).

We stipulate that tone sandhi rules are in fact the historical products of tonal coarticulation, and the phonological aspect of tone sandhi rules is either to show greater contrast between adjacent tones or to ease the effort of articulation.

To sum up, both the phonetic realizations of tonal representations and tonal coarticulation effect in Ta-pu Hakka aim to show either harmony or contrast. The phonetic realizations of tonal representations and coarticulation in this language also help group all the tones into different natural classes: such as non-falling vs. falling, and non-checked vs. checked.

Keywords: Hakka, Ta-pu Hakka, tonal representations, tonal coarticulation, tonal context, phonological and phonetic interface

中文摘要

本研究主要研究兩個問題：(1)調查聲調在音韻學系統及其語音學上的表現之相關性; (2)調查聲調在一組連續發聲出來的雙字詞中，所產生的聲調聲學特徵的細微變化。

台灣目前有兩大客語系統：海陸腔及四縣腔，但除此之外，其實也還有許多其他的次方言。其中一種，是客家話大埔音，目前大約有六萬人會使用大埔客語，而這些人口目前主要分布在台灣的中部三鄉鎮：東勢，石岡及新社。不同的次方言是以不同的聲調系統或是用字來作區辨，然而，在之前文獻中所使用的大埔客語的聲調系統多是根據聽覺所標記出來的，而非根據聲學所計算出來的，最多只能呈現出一般人對此聲調系統的聽覺印象。

因此，本研究將從客觀之物理聲學角度來檢視大埔客語的聲調系統，透過單字詞與雙字詞，我們將分析大埔客語的本調調值及變調調值，另外，在雙字詞組中，我們也探索了本調調值在前字及後字的位置中，是否和在單字詞中所計算出來的調值有所不同。在重新檢視大埔客語的聲調系統之後，我們將緊接著探討聲調在一組連續發聲出來的雙字詞中，所產生的聲調聲學特徵的變化。「聲調連發」是指在一連串連續不斷的發音中，相鄰的聲調會因而產生的變化，這也是許多語音學家近幾年來研究的重點。而本研究將探討的是雙字詞的「聲調連發」現象，欲調查雙詞中的聲調在詞首及詞末會如何變化；此外，我們也將雙字詞組根據許毅(1994)的分類，將雙詞組的聲調組合分別歸類於調值相近或相斥的組合；接著，我們再細看調與調之間的相互作用。在探討「聲調連發」的過程中，我們也採用了許毅的「目標近似模型」，來看大埔客語中所發現的聲調變化現象。

為了回答我們所提出的兩個研究問題，本研究所量測的聲學特徵參數包含音節的起始點及終點的基頻，最大及最小基頻，以及整個音節包含子音部分的平均基頻、斜率及音長。而對於陽平調，我們也檢視了它「最小基頻」出現在「音節」部分的相對位置，因為這個參數將影響陽平調的調型。音節的起迄點及最小基頻將作為計算調值的參考點，而在探討「聲調連發」時，所有的參數都會用來調查聲調的聲學變化。在計算調值的公式上，我們將比較兩種不同的版本，一是馮怡蓁博士及江文瑜博士在 1999 年的研究中所採用的公式，另一方面，我們也採用了石鋒(1990)的對數公式來做比較。

透過公式的計算，我們發現，馮與江計算出來的調域是屬於非線性的，而石鋒的公式算出來的調域呈現接近線性的關係，因此，本研究中，我們將採計使用馮與江的版本所得到的結果。根據聲學觀察與計算的結果，大埔客語的聲調調值在單獨發音時應該修正為：陰平 33，陽平 313，上聲 31，去聲 53，超陰平 34，陰入 3，陽入 4(底線表示促調)；而在雙字詞中，我們發現根據此組資料計算出來的調值不適宜當作大埔客語聲調的調值。至於變調的調值，我們發現採用石鋒的公式所計算出來的調值反而比較符合統計的結果，其計算出來的陰平變調為 324，陽平變調為 323，而去聲變調為 44。然而，變調的調值實際上已經受到了其相鄰聲

調的影響，因此在之後調查「聲調連發」的研究中，對於變調調值，我們還是會採用在原本文獻中所使用的調值來做分類，這三個變調原本的調值分別是 35，33，55。透過聲學的參數，我們發現陽平調實際上並非真正的平調，而是先降後揚的凹型調。大埔客語的七個主調，加上三個變調，總共有十個聲調，這十個聲調大多可配成對，若其中一個是屬於高頻區，那另一個則屬於低頻區。其中我們注意到兩個入聲調的調值非常接近，但統計結果顯示 4 比 3 的基頻來得高，而 3 的斜率比 4 來的陡峭，這個結果與張月琴在 1995 年根據苗栗四縣客語所做的研究結果相同。

在針對第二個研究問題「聲調連發」進行多種面向的探討之後，我們發現，除了上聲[31]及陰入[3]之外，其餘所有聲調在詞尾的調長都比較長，有「詞尾拉長」的情形出現，而上聲[31]及陰入[3]反而是在詞首的調長比在詞尾時來得長。在斜率方面，這兩個調在詞尾的下降斜率都比較大，有一種「突如其來的下降」的現象，或許也正是因為這種「突如其來的下降現象」造成調長的縮短；但超陰平[34]這個揚調的斜率，反而是在詞首的位置時顯的較為陡峭，表示揚調在詞首的位置有拉長的現象出現。陽平調[313]的調型則是在不同的位置，有不同的調型產生：在詞首，陽平調[313]會較接近降調，而在詞尾，它仍會是個凹型調，只是音節的起迄點略較單字詞時降低。

而在採用許毅的調值相容與相斥的聲調環境的分類法時，我們發現大埔客語其實還存在有一種特殊的聲調環境——調型相容，所謂的調型相容是指降調加上揚調，或是揚調加上降調這樣的組合。雖然我們所定義的調型相容對許毅而言，是屬於調值相斥的環境，但我們研究的結果發現，大埔客語中的調型相容的環境其實是類似於調值相容的環境，兩者對聲調的影響是類似的。

另外，在我們分別看每一個聲調對其相鄰的聲調有何影響時，我們發現了三種聲調變化：(1)前字詞對後字詞造成目標近似的影響（持續保留的目標近似）；(2)後字詞對前字詞造成目標近似的影響（預期的目標近似）；及(3)後字詞對前字詞造成目標對比分化的影響（預期的目標對比）。第一類包含了陰平[33]，陽平[313]，去聲[53]，及陽入調[4]，第二類包含上聲[31]，去聲[53]及陰入調[3]，而陽入調的聲調變化其實囊括這三類所有的變化。在第一及第二類的變化當中，我們發現了前字詞的迄點調值與後字詞的起點調值之間，有正比的關係存在，這現象也可以用許毅的「目標近似模型」來解釋，也就是相鄰兩點的調值會互相接近。然而，第三類的聲調變化卻無法用此模型來解釋，因為這種變化是一種相鄰兩點的調值互斥的結果，這個互斥現象是為了顯現出兩個調之間的反差與對比。這種調與調之間的互斥現象其實早就存在於大埔客語的變調系統中，例如：陰平後面若是跟著一個上聲，則陰平[33]會變成上揚調[35]，為的就是要拉開與後面上聲起點調值的距離以增強對比。我們相信，變調在音韻化之前，其實是長久以來的「聲調連發」的結果，當某個聲調因為連發時所造成的變化，已經大到可用聽覺直接歸類為另一個調時，音韻學上的變調便因此產生了。

總而言之，本研究透過聲調的聲學研究結果，發現了大埔客語聲調系統的兩

個重要特性：亦即「和諧共存」與「反差對比」，這兩個特性也展現在客家人的「硬頸」精神中——那種為了融入新環境所做的努力，但同時又保留了客家人勤奮節儉的本色。

關鍵詞：客家話（客語），大埔客語，聲調系統，聲調連發，聲調環境，音韻學與語音學的分界

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Chapter 1 Introduction

1.1 Introduction

Tone language is defined as "a language having lexically significant, contrastive, but relative pitch on each syllable" by Pike (1948, p.3). Tone languages are spoken in many places in the world. The regions classified by Yip (2002) include Africa, East and South-East Asia and the Pacific, and the Americas. Each tone language has its own unique way of representing tones, which varies with regions. Hakka, the target language in this thesis, is also a tone "language." It is in fact one of the dialects in Chinese language. Ta-pu Hakka, one of the sub-dialects in Hakka, is of special interest in this study.

In this study, two levels in regard with tones in Ta-pu Hakka will be investigated (for details of Ta-pu Hakka, see Section 1.2).[1] The first research question is to investigate the phonological representations and the phonetic realizations of the tones in Ta-pu Hakka, and the second is to explore the tonal coarticulation effect in disyllabic-word combinations.[2]

1.1.1 First Research Question: Tonal Representations and Phonetic Realizations

In previous literature with regard to the tonal representations in Hakka, most of the tonal representations were based on phonological descriptions via auditive perception, and they were hence more impressionistic. As a result, if acoustic data are taken into consideration, there will probably be some incongruence between the phonological representations and phonetic realizations. There were some studies that focused on phonetic realizations of tones in Mandarin and Hakka (Chang, 1995; Fon & Chiang, 1999; Huang, 2003).[3] Via acoustic data, tonal representations were found to be different to some extent from the original tonal representations which were based on auditive perception and phonological descriptions.

Phonologically, for example, the long-existing consensus on tonal representations in Mandarin Chinese is shown numerically in a system known as “Chao tone letters,” based on work by Chao (1930). In fact, the “Chao tone letters” are numbers, not letters, which divide the natural pitch range of the normal speaking voice into five levels, with 1 as the lowest and 5 as the highest.[4] The five-scaled “Chao tone letters” system will be used throughout this paper to denote the tonal representations of Mandarin Chinese and other dialects of Chinese language mentioned. As for Mandarin, there are four tones in this language, and they are commonly referred to as Tone1, Tone2, Tone3, and Tone4 by Chinese people and linguists. The tonal scales (abbreviated to T-scale) of the four tones are [55], [35], [214], and [51] according to Chao’s designation.

Though Chao’s five-scaled system has set up the foundation of Chinese tonology, it is a fact that no available acoustic analysis could have been implemented at that time. Therefore, Fon and Chiang (1999) found it was a must to look into the correlation between Chao's tonal scale system and the acoustic realizations of tones in Taiwan Mandarin. [5] In order to investigate the incongruence between phonological representations and phonetic realizations, Fon and Chiang reconstructed and postulated formulae based on Chao's analogizing the five reference points with musical notes (Chao, 1968). With these postulated formulae, which included four equations, Fon and Chiang found that the realizations of Mandarin tones via acoustic data gathered from monosyllabic and tri-syllabic words were in fact different from the original phonological representations(for details of Fon and Chiang's formulae, see 2.2.1).

Chang (1995) and Huang (2003) investigated the correlation between the phonetic realizations and the phonological representations in Suu-hsien Hakka.[6] Via acoustic data, they also found that the revised tonal representations in Suu-hsien Hakka were different from the original phonological representations.

In Huang's study in Hakka, he investigated the acoustic realizations of tones in Ssu-hsien Hakka spoken in Mei-nung, a township in Southern Taiwan. Unlike Fon and Chiang's study, he adopted Shi's (1990) logarithmic function directly to verify the tonal representations via monosyllabic and disyllabic words (see 2.2.2 for detailed discussion of Shi's function). The study showed that the tonal representations of the Southern

Ssu-hsien Hakka via acoustic data were different from the original ones. The revised T-scales of the tones in Suu-hsien Hakka were suggested by the author as follows: 32 for *Yin-Ping* (T1), 31 for *Yang-Ping* (T2), 42 for *Shang* (T3), 55 for *Chü* (T4), <u>53</u> or <u>43</u> for *Yin-Ju* (T5), and <u>55</u> for *Yang-Ju* (T6).[7] However, we found that the revised tonal representations were not very easy for speakers to distinguish one from another because the distance between two tones was too short. For example, Tone1[32] and Tone2[31] both exhibited falling slope, only that the slope of Tone2 seemed to be steeper than Tone1. In Huang's study, he found that both level tones and falling tones exhibited falling slope, but the falling slope of a falling tone was steeper than that of a level tone. However, the distance between Tone1 and Tone2 was so short that it might not be easy even for a native speaker to pronounce words carrying the two tones correctly. Though Huang did find incongruence between phonological representations and phonetic realizations, the revised tonal representations suggested in his study were even more likely to confuse the speakers of this language.

The results of Chang's (1995) study showed the same problem in the revised tonal representations. The revised tonal representations of Miao-li Suu-hsien Hakka were suggested as follows: 35 for *Yin-Ping*, 31 for *Yang-Ping*, 51 for *Shang*, 55 for *Chü*, <u>52</u> for *Yin-Ju*, and <u>55</u> or <u>53</u> for *Yang-Ju*. As can be seen from the revised version, the tonal scales (T-scale) of *Yin-Ju* and *Yang-Ju* were actually very close to each other. As a result, the two revised tones were even harder for a native speaker to distinguish one from the other. This result also raised the question as to the validity of Shi's logarithmic function.

The incongruence between phonological representations and phonetic realizations found in those studies demonstrated the fact that not only auditive perception and impression but also acoustic realizations should be taken into consideration when describing tones. The interesting findings in Mandarin Chinese and in Hakka have raised our interest in exploring and verifying the acoustic tonal representations of Ta-pu Hakka, which is spoken mainly in central Taiwan. In order to find a better way to verify the tonal representations via acoustic data, we will compare the tonal representations of Ta-pu Hakka revised based on Fon and Chiang's formulae and Shi's logarithmic function.

In order to answer the first research question, two sets of word inventories will be used in this study: the first is a set of monosyllabic words, and the second is a set of disyllabic words. The same kind of stimuli was also adopted by Chang (1995) and Huang (2003) to explore the phonetic realizations of tones in isolated syllable, and in word-initial and word-final positions. However, in Fon and Chiang (1999), they used monosyllabic and tri-syllabic words to investigate the phonetic realization of tones in isolated syllable, and in word-initial, word-medial, and word-final positions. The inventory of monosyllabic words in this study will be used to set up the tonal representations of citation tones (CT). As for that of disyllabic words, they are used to set up those of sandhi tones (ST) as well as tonal representations in different prosodic positions. The prosodic positions here in disyllabic words refer to a syllable in the word-initial position (WI) and that in the word-final position (WF). Shen & Lin (1991) claimed that "the acoustic properties of tones in isolated citation form are not appropriate for use as norms in investigating tones in connected speech" (p. 431). However, we believe that to some extent, tones in multi-syllabic words are modified or changed by the tonal contexts they are in. As a comparison, we would like to explore whether the citation tones in isolation or in multi-syllabic words should be regarded as the norms in Ta-pu Hakka.

As for the calculation of T-scales, we will compare two kinds of methodologies: the first one is the formulae postulated and reconstructed by Fon and Chiang (1999), and the second is the logarithmic function proposed by Shi (1990). The two methodologies are briefly illustrated in (1) and (2). Detailed explanations of the two methodologies will be discussed in Section 2.2.

(1) Fon and Chiang's version of calculating T-scales of Mandarin tones:

(a) Hz→Semitone: Semitone (N)=39.86∗log($f_i - f_{min}$)
(b) *Tone#* = N/2+1 (if N≧3)
(c) *Tone#* = Tone3 (if 2.5≦N<3)
(d) *Tone#* = Tone2 (if 0.5≦N<2.5)
(e) *Tone#* = Tone1 (if 0≦N<0.5)

(2) Shi's logarithmic function:

T-scale= 5 ∗ (log**χ**-log***b***)/(log***a***-log***b***)

("***a***" represents the maximum F0 measured, "***b***" the minimum F0, and "**χ**" the F0 of the target point, i.e. the F0 of BP, EP, peak, and valley)

1.1.2 Second Research Question: Tonal Coarticulation Effects

After we verify the phonetic tonal representations and set up the norms of tonal representations in Ta-pu Hakka, we will further explore the interactions and variations of those citation tones when they are coarticulated. Tones are found to coarticulated in consecutive speech. Xu (2004) gave a clearer definition of tonal coarticulation, "Tonal coarticulation usually refers to tonal variations that are strictly conditioned by tonal context and are ***phonetically*** motivated" (p. 783). Xu (2004) also mentioned that it was to some extent not so easy to separate tonal variations due to coarticulation from those due to tone sandhi. According to Gussenhoven (2004), "historically, tone sandhi must have originated in allophonic variants of tones which came to resemble other tones of the language and were subsequently equated with them" (p. 36). Thus, in the present study, we will try to explore the correlation between tonal coarticulation and tone sandhi and see if there are some overlaps or incongruence between the two types of scope. We assume that tonal coarticulation is driven by phonetic and articulatory motivation, and tone sandhi is the result of allophonic variations of tones resulted from tonal coarticulation.

In this study, some questions regarding coarticulation effects need to be answered. The first tonal coarticulation effect would be caused by different prosodic positions where a tone is positioned in disyllabic words in this study (Section 2.3.1). Second, how tonal contexts, namely a compatible or a conflicting context, may influence the tonal coarticulation will be discussed (Section 2.3.2). Third, we would like to know how a particular tone will influence its neighboring tone (Section 2.3.3). Finally, we would also try to explore whether the effect of tonal coarticulation in Ta-pu Hakka is anticipatory or carryover, or even both and to investigate whether the effect is assimilation or dissimilation.

Xu mentioned that the notion of dividing tonal contexts into a compatible or a conflicting context was somewhat archaic (personal communication, June 21, 2007). That was why he has developed a new model for the last decade, termed as Target Approximation model (TA model), to describe tonal variations found in Mandarin (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001). We will also introduce this model in our study and see if this model is able to explain the tonal variations found in Ta-pu Hakka (For details of Xu's TA model, see Section 2.3.4).

1.2 Introduction to Ta-pu Hakka

In this section, we will introduce the background information of Ta-pu Hakka in regard with the original tonal representations in Section 1.2.1. The syllable structure will be introduced in Section 1.2.2, and then we will briefly introduce the consonants and vowels in this language in Section 1.2.3. As for tone sandhi rules in disyllabic words, they will be explicitly introduced in Section 1.2.4.

1.2.1 Tones in Ta-pu Hakka

The target language under investigation in this study is Ta-pu Hakka, also called as a "***sub-dialect*** of Hakka" in Chinese phonology. There are two other major sub-dialects of Hakka spoken in Taiwan: the Hai-lu Accent and Ssu-hsien Accent.[8] Those sub-dialects differ not only in morphemes but also in tonal systems because they are spoken in different regions and diversities hence occur. Ta-pu Hakka accent is spoken mainly in three townships in central Taiwan. Now there are about 60,000 Ta-pu Hakka speakers living mainly in Tung-shih, Shih-kang, and Hsin-she. Ta-pu Hakka used to be categorized as Jao-ping Hakka (Lo, 1990). As a matter of fact, the accent called Jao-ping by Lo is spoken only in an administrative area called Fu-lung in Tung-shih. Afterwards, Chung (2004) categorized it as Ta-pu accent, which is now a consensus to Ta-pu Hakka speakers.

To understand Ta-pu Hakka accents, we first have to understand the tonal system and their representations since tones play a role of distinguishing one sub-dialect from another in Hakka language. In previous literature, different T-scales were adopted by different scholars. Table 1.1 shows the tonal representations used in different resources. The ***Ta-pu Hakka Dictionary*** in this table refers to the first comprehensive dictionary of Ta-pu Hakka published in 2005 and it collected a large inventory of Ta-pu Hakka words (Shü, Liu, & Chang, 2005). In the present study, all the monosyllabic words and disyllabic words will be chosen from the words in this dictionary.

Table 1.1: Tonal representations of Ta-pu Hakka tones in different resources

Tone name	***Yin-Ping***	***Yang-Ping***	***Shang***	***Chü***	***Yin-Ju***	***Yang-Ju***	***Supra-Yin-Ping***
Tone type	mid-level	low-rising	low-falling	high-falling	low-checked	high-checked	high-rising
Lo (1990)	44	112	31	53	21	55	35
Tung (1995)	33	113	31	53	32	5	35
Chiang (1998)	33	113 / 11	31	53	31	5	35
Ta-pu Hakka Dict. (2005)	33	113	31	52	2	5	35

As can be seen from Table 1.1, the tonal representations show a wide diversity among different scholars. For example, the T-scales assigned to the low checked tone are totally different. As for *Yang-Ping* tone, it is even designated as [113] or [11] by Chiang in her two studies in 1998. The two different scales in fact represent two kinds of tonal types: the former is a low-rising tone, whereas the later is a low-level tone. Nevertheless, all the four kinds of tonal representations in previous literature were based merely on auditive perception. That is, no previous studies of Ta-pu Hakka tones based on acoustic data have ever been conducted.

Table 1.2: Phonological tonal representations in Ta-pu Hakka (CT: citation tone; ST: sandhi tone. The T-scale used in this table is adopted from *Ta-pu Hakka Dictionary* for easy reference.)

	Tone No.	Tone Name	Phonological Descriptions	T-scale (Hakka Dict.)	Example
	T1[9]	*Yin-Ping*	Mid-level (M)	33	*[tʃ^h a]33* ‘sew’
	T2	*Yang-Ping*	Low-level-rising (LLM)	113	*[k^{h}jɛn]113* ‘power’
	T3	*Shang*	Mid-falling (ML)	31	*[k^{h}jɛn]31* ‘angry’
CT	T4	*Yin- Chü*	High-falling (HL)	52	*[k^{h}jɛn]52* ‘to persuade’
	T5	*Yin-Ju*	Low checked tone (L)	2	*[k^{h}jɛt]2* ‘to lack’
	T6	*Yang-Ju*	High checked tone (H)	5	*[k^{h}jɛt]5* ‘outstanding”
CT & ST	T7	*“Supra”-yin-ping*	High-rising (MH)	35	*CT: [tʃ^h a] 35* ‘car’ *ST:[k^{h}ɔɪ]33_[mun]113* *→[k^{h}ɔɪ]35_[mun]113* ‘to open the door’
ST	--	--	Mid-level (M)	33	*[p^{h}u]113_[t^{h}o]113* *→[p^{h}u]33_[t^{h}o]113* ‘grapes’
	--	--	High-level (HH)	55	*[p^{h}jɛn]52_[so]31* *→[p^{h}jɛn]55_[so]31* ‘toilet’

Table 1.2 presents the examples in each tone entry. We assign the tone numbers into each tone according to the order of four ***Sheng*** “sound” in Chinese phonology:

Pin-Sheng, Shang-Sheng, Chü-Sheng, and Ju-Sheng. And they are further sub-divided into *Yin* and *Yang.* The column of phonological descriptions represents the tone types along with their tonal interpretations in parenthesis (Gussenhoven, 2004, p.27-28). As we can see from Table 1.2, there are one level tone, two rising tones, two falling tones, and two checked tones in Ta-pu Hakka. T2[113] is considered to have longer duration, so it is designated with a three-digit tonal scale.[10] T5[2] and T6[5] have an underline in their T-scales, indicating that they are tones which end with a final stop coda ([p], [t], or [k]) and have a shorter duration. The two tones are called checked tones in Chinese phonology. The T-scales shown in this table refer to those used in ***Ta-pu Hakka Dictionary*** for easy reference (Shü et al., 2005).

According to Yip (2002), if there are two falling tones in a language, there are at least three level tones, high-level, mid-level, and low-level, in that language. It seems that tones in Ta-pu Hakka do not to fit in her claim. However, if we take sandhi tone into consideration, we can see that the sandhi tone of Tone4[52] will be Tone[55]. As can be seen in Table 1.1, Tone2[113] was considered as a kind of low-level tone by Chiang (1998b). Thus, we might be able to categorize the eight tones (including sandhi tone of *Chü Sheng*) as follows: three level tones, Tone2[11] (low), Tone1[33] (mid), and Tone[55] (high); two falling tones, Tone4[52] (high falling) and Tone3[31] (low falling), and two checked tones, Tone6[5] (high checked) and Tone5[2] (low checked). The phonological tonal representations in Ta-pu Hakka indicate that the tonal system in Ta-pu Hakka is quite complete and equally distributed within the tone type dimension.

Yip (2002) claimed that if there are two falling tones in a language, [53] should be a better representation for the high falling tone and [31] for the low falling tone, with 3 in the middle of the five-scale system. In Table 1.1, we can see that the two falling tones were assigned as [53] and [31] in the former three studies, whereas the high falling tone was designated as [52] in ***Ta-pu Hakka Dictionary***. In order to explore the phonetic realizations of Ta-pu Hakka tones, this study will try to investigate if the tonal representations of the two falling tones in Ta-pu Hakka will support Yip's claim when acoustic data are taken into consideration.

1.2.2 Syllable Structure of Ta-pu Hakka

The syllable structure in Ta-pu Hakka is the same as other dialects in Chinese. This structure basically includes consonant (initial), medial (semi-vowel), vowel (nucleus), and tone. The internal structure of a syllable in Ta-pu Hakka is illustrated in Figure 1.1.

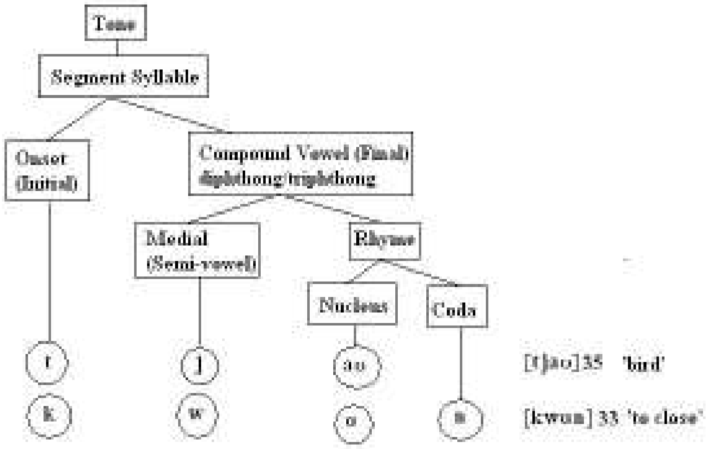


Figure 1.1: Syllable structure of Ta-pu Hakka
(Chung, 2004, p. 56)

Figure 1.1 shows the basic syllable structure of Ta-pu Hakka. This syllable structure is translated directly from Chung's Chinese version of Hakka syllable structure. In a syllable, which consists of tone, onset consonant (initial), medial (semi-vowel), nucleus, and coda, only tone and nucleus are obligatory, and all the other elements are optional.

Chung (2004) considered that the tone-bearing unit (TBU) in Hakka was associated to the whole syllable.[11] Previous literature in regard with the tone study has been arguing whether TBU should be the whole syllable or the vowel only. For example, in Mandarin Chinese, the medial, or the semi-vowel, was considered as non-syllabic vowel in Howie's (1974) study of tones in Mandarin. He claimed that the domain of Mandarin tone was confined to the syllabic vowel and any voiced segment that may follow it in the syllable, which was the ***rhyming*** part of the syllable. However, in other literature, medial along with the rhyme were considered to have contribution in determining the tone (Kratochvil, 1970; Cheng, 1966). Kratochvil (1970) and Cheng (1966) both considered that it was the final that carries the relevant tone pitch. They believed that some initials, [m], [n], [l] or [r], may carry pitches, but their values were irrelevant in determining the tones. However, Chao (1968) and Xu (1994, 1997, 1999, 2004) both claimed that if the initial is voiced, the tone begins with the initial and spreads over the whole syllable. On the other hand, if the initial is voiceless, the tone is spread over the final only. Shen and Lin's (1991) study found that in connected speech, not only the syllabic vowel and its voiced coda but also the initial consonant or non-syllabic vowel (medial) were all influenced by tonal coarticulation. What is worth noticing is that all the above assumptions were based on the studies and observations of Mandarin tones.

As for tones in Ta-pu Hakka, whether the TBU is associated to the whole syllable, to the final, or even to the rhyme remains unsolved. More acoustic studies of Hakka tones are needed in order to answer this question. As for the present study, we will try to choose words with voiceless onsets as possible as we can, so the initials can be truncated because voiceless initials will not carry pitch values. If voiced initials are chosen, the pitch values of the initials will be included in the measurement. Therefore, all the parameters measured in the present study will be confined to the whole syllable.

In Figure 1.1, two examples are given to show words that include an onset, a medial, a nucleus, and with or without a coda. *[tjaʊ]35* ‘bird’ does not have a coda but has a diphthong in the nucleus, whereas *[kwan]33* ‘to close’ is a syllable with a nasal coda. Thus, in *[tjaʊ]35*, only the final of the syllable, *[-jaʊ]*, will be measured, while in *[kwan]33*, only *[-wan]* will be measured because the two initials are both voiceless and there will be no pitch value being able to be fetched. Possible combinations of the four segments, initial, medial, nucleus, and coda, will be presented in Section 1.2.3.

1.2.3 Consonants and Vowels in Ta-pu Hakka

After having a preliminary understanding on tones and syllable structure in Ta-pu Hakka, we will further introduce the consonants and vowels. There are totally twenty consonants in Ta-pu Hakka, and six of the consonants can also appear after vowels as codas. The codas in Ta-pu Hakka include three stops [p], [t], [k] and three nasal consonants [m], [n], [ŋ]. A syllable with a stop coda is called a checked tone in Chinese phonology. Table 1.3 shows the consonants and their corresponding IPA used in this thesis.

Table 1.3: Spelling of the consonants used in *Ta-pu Hakka Dictionary* (Shü et al., 2005) and their corresponding IPA. (Dict.=*Ta-pu Hakka Dictionary*.)

Dict.	b	p	m	f	v	d	t	n	l	g
IPA	[p]	[pʰ]	[m]	[f]	[v]	[t]	[tʰ]	[n]	[l]	[k]
Dict.	k	ng	h	zh	ch	sh	rh	z	c	s
IPA	[kʰ]	[ŋ]	[h]	[tʃ]	[tʃʰ]	[ʃ]	[ʒ]	[ts]	[tsʰ]	[s]

We will not adopt the spelling suggested in this dictionary although it is the first and the most thorough Ta-pu Hakka dictionary that has ever been published. In this study, IPA will be used to transcribe all the words used in this thesis because it is easier to pronounce for the readers.

As has been discussed in Section 1.2.2, the consonants are not obligatory according to Hakka syllable structure. In other words, some words do not require an initial consonant, and *[am]52* 'dark' is one of the examples.

As for the final of a syllable, it includes the medial (semi-vowel), the vowel, and the coda. There are two medials, [j] and [w] in Ta-pu Hakka. Table 1.4 presents possible combinations of the final in a syllable. There are six single vowels,/ɨ /, /ɑ/, /e/, /i/, /o/, and /u/, and four diphthongs, [aɪ], [aʊ], [ɔɪ], [ɛʊ].[12] There are three other possible combinations of the compound vowel (the final): (A) a semi-vowel plus a vowel; (B) a vowel plus a coda, and (C) a combination of a semi-vowel, a vowel, and a coda. To sum up, there are sixty-one possible combinations of the final.

Beside vowels, the three nasals, [m], [n], and [ŋ], can also be syllabic and their examples are given in Table 1.5. Note that the syllabic nasals will not be selected into the word inventory in our study.

Table 1.4: Possible combinations of the final in a syllable in Ta-pu Hakka

<table>
<tr><th>Segments of the rhyme</th><th>Individual item in each segment</th><th>(A)
semi-vowel (medial)
+ vowel</th><th>(B)
vowel + coda</th><th>(C)
semi-vowel
+ vowel +
coda</th></tr>
<tr><td>complex onset (semi-vowel)</td><td>[j], [w]
(not counted)</td><td rowspan="2">[jɑ], [je], [jo], [ju] [wɑ], [we], [wi], [jaʊ], [jɛʊ], [waɪ], [jɔɪ]
(11 items)</td><td></td><td rowspan="3">[jɛm], [jɑm], [jɛn], [wɑn], [jɔn], [jun], [jɑŋ], [wɑŋ], [jɔŋ], [jʊŋ], [jɑp], [jɛt], [wɑt], [jɔt], [jʊt], [jɑk], [jɔk], [jʊk]
(18 items)</td></tr>
<tr><td>vowel</td><td>[ɨ], [a], [e], [i], [o], [u]
[aɪ], [aʊ], [ɔɪ], [ɛʊ]
(10 items)</td><td rowspan="2">[ɑm], [ɑn], [ɑŋ],[ɑp], [ɑt], [ɑk], [ɛm], [ɛn], [ɛp], [ɛt] [ɪm], [ɪn], [ɪp], [ɪt], [ɔn], [ɔŋ], [ɔt], [ɔk], [un], [ʊŋ], [ʊt], [ʊk]
(22 items)</td></tr>
<tr><td>coda</td><td>[m], [n], [ŋ], [p], [t], [k]
(not counted)</td><td></td></tr>
</table>

Table 1.5: Syllabic consonants

Spelling in ***Ta-pu Hakka Dictionary***	IPA	Examples
m	[m̩]	*[m̩]113* “not…” as in *m113_he52* “No!”
n	[n̩]	*[n̩]113* “you”
ng	[ŋ̍]	*[ŋ̍]113* “fish” *[ŋ̍]31* “five”

1.2.4 Tone Sandhi Rules of Disyllabic Words

In Ta-pu Hakka, there are many tone sandhi rules occurring in disyllabic, tri-syllabic, and even tetra-syllabic words (Chiang 1998a, 1998b, 2002; Hsiao & Chiu, 2006). We will only present the tone sandhi rules in disyllabic words because the word inventory adopted in this thesis is disyllabic words at most. In a disyllabic-word combination, there are only three tones that tone sandhi rules will be applied to:

Tone1[33], Tone2[113], and Tone4[53]. The rules are stated as follows. All the T-scales in brackets are original tonal representations used in ***Ta-pu Hakka Dictionary*** (Shü et al., 2005).

(3) ***Yin-ping Tone Sandhi:*** Tone1[33]→Tone7[35]／__{Tone3[31], Tone2[113], Tone5[2]}
(4) ***Yang-ping Tone Sandhi:***Tone2[113]→Tone1[33]／__Tone2[113]
(5) ***Yin- Chü Tone Sandhi:*** Tone4[52]→Tone[55]／__{Tone4[52], Tone6[5], Tone3[31], Tone5[2]}

Rule (3) means that the T-scale of ***Yin-ping Tone***, ***Tone1[33]***, becomes [35] when followed by Tone3[31], Tone2[113], or the low checked tone Tone5[2]. The descriptions of (4) and (5) are the same. What is worth noticing is that the result of Rule (4), Tone1[33] followed by Tone2[113], will not undergo Rule (3) again. All the sandhi rules will occur only once in a particular kind of tonal combination. When we look into Rule (3) and Rule (4), they occur when Tone1[33] and Tone2[113] are followed by a particular tone, indicating an "anticipatory dissimilation effect." Also, we have noticed that rule (5) indicates not only anticipatory dissimilation when followed by Tone3[31] and Tone5[2], but also "anticipatory assimilation effect" when followed by Tone4[52] and Tone6[5]. Rule (4) is in fact similar to the Mandarin Tone3 Sandhi, that is, Mandarin Tone3[214] becomes Tone2[35] when preceding another Tone3[214]. The Mandarin Tone Sandhi can be seen as the repair of a violation of the Obligatory Contour Principle, created by the sequence of two L-tones (Yip, 2002). Therefore, Rule (4) also occurs because of the sequence of two L-tones.

From the observation of tone sandhi rules in Ta-pu Hakka, we will compare the sandhi rules with the results of tonal coarticulation in this study. The results of the present study suggest that anticipatory effect is not only dissimilated but also assimilated in Ta-pu Hakka, which is very similar to the phenomena of tone sandhi rules discussed above.

1.3 Contributions of the Two Studies on Phonological Theory

In this study, the investigation of the correlations between phonological representations and phonetic realizations of Ta-pu Hakka tones, and the exploration of tonal coarticulation via acoustic data have provided three contributions for the study of phonetics and phonology. First, in empirical aspect, this study is the first acoustic study that has ever been conducted to investigate the realizations of tones in Ta-pu Hakka. The results of the revised tonal representations not only show the contrast between tones but also demonstrate the phonetic characteristics and realizations of Ta-pu Hakka tones.

In methodology, the tonal representations are revised and verified via comparing two kinds of calculating methods. We not only adopted Fon and Chiang's (1999) original version of formulae but also adjusted and reconstructed those formulae according to the average pitch range of our six informants. We use the average pitch range because it is considered to represent a speaker's natural speaking pitch range. Therefore, this modification is necessary to make the revised tonal representations more equally distributed to the five scales based on Chao's (1968) assumption of this system (for details, see Chapter 3). The revised tonal representations of Ta-pu Hakka via acoustic study are different from the original phonological representations based on auditive perception. The incongruence between phonological representations and phonetic realizations shows that any phonological descriptions should take the results and realizations from phonetic study into consideration. Besides, the reason why we have reconstructed Fon and Chiang's formulae according to different pitch ranges because we assume that the T-scales should be able to represent a kind of comparative correlation of a speaker's or a group's natural speaking pitch range instead of an absolute correlation. That is, no matter how large the pitch range of a speaker is, the revised tonal representations should be able to indicate the five reference scales.

In theoretical consideration, we have reexamined the definition of compatible and conflicting contexts because Ta-pu Hakka is a language with more tones and more possible tonal combination than Mandarin. We suggest that if the pitch contours of two adjacent tones are compatible with each other, that is, [Rise]_[Fall] or [Fall]_[Rise], the two tones should be considered as having a "***contour compatible context***", which is the third kind of tonal contexts other than the two contexts defined by Xu (1994). For example, Tone7[35] followed by Tone3[31] should be considered as having a ***contour compatible context***. Furthermore, we have found that classifying tonal combinations into compatible or conflicting contexts can not completely show the tonal variations in Ta-pu Hakka. Tones in Ta-pu Hakka have been found to be affected by their neighboring tones and the prosodic positions. As for Xu's Target Approximation model (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001), the results of this study indicate that the tonal variations in Ta-pu Hakka can not be explained completely by using the TA model.

1.4 Organization of this Thesis

The remainder of this thesis will be organized as follows. We will introduce the methodology adopted in this thesis in Chapter 2. Section 2.1 will introduce the word inventories that are selected. Section 2.2 will introduce the two versions of calculating T-scales. Section 2.3 will introduce the methodology and the domains of tonal coarticulation which will be investigated in this study. Then the subjects and recording procedure will be presented in Section 2.4. In Section 2.5, we will explicitly define the parameters measured in order to answer the two research questions in this study.

Afterward, the revised tonal representations will be presented in Chapter Three. Citation tones and sandhi tones will be discussed as well as the tonal representations of syllable 1 (word-initial position) and syllable 2 (word-final position) in disyllabic words. In Section 3.1, tonal representations of citation tones via monosyllabic words will be explored. We will also compare the results from adopting Fon and Chiang's formulae (1999) and Shi's logarithmic function (1990), and then we try to find out which one is more suitable for verifying tonal representations. In Section 3.2, tonal representations of sandhi tones will be verified along with the tonal representations of tones in WI and WF positions.

In Chapter Four, we will discuss the tonal coarticulation according to different effects: prosodic contextual effects, tonal context effect, and adjacent tone effect. The Target Approximation model will be used as reference through the discussion of the three types of coarticulation effects (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001). We will summarize and discuss the findings of the two research questions in this thesis in Chapter Five. Some shortcomings and insufficiencies of this study will also be pointed out, along with the suggestions for future research.

Notes:

[1] There are three types of spelling used in this thesis:
(1) author names: according to the spelling provided by the authors themselves in their papers or spelled in Wade-Giles; (2) other proper names such as place names and Chinese words: in Wade-Giles; (3) Hakka words: in IPA.

[2] Tonal representations in this study refer to all the phonological and phonetic description of tones, including the tone name, the tonal type, the tonal interpretation, and the numerical T-scales, whereas T-scale refers to the numerical tonal notations via "Chao tone letters.

[3] Fon and Chiang (1999) is an extension of Fon's unpublished master thesis in 1997.

[4] In Mandarin Chinese, each syllable is given zero to three digits, usually written after the segmental transcription and often, but not always superscripted. Zero digits means that the syllable bears no phonological tone of its own. Usually, each syllable is given two digits, the first indicating the starting point, whereas the second indicating the ending point. If a syllable is given three digits, it means that there is a fall or a rise in the middle of the syllable.

[5] Taiwan Mandarin was termed by Fon and Chiang (1999) to represent the Mandarin spoken in Taiwan. It was different from Taiwanese Mandarin, which meant a kind of Mandarin with Taiwanese accent.

[6] Chang (1995) investigated the tonal representations in Miao-li Suu-hsien Hakka (Northern Suu-hsien Hakka), whereas Huang (2003) investigated those in Mei-nung Suu-hsien Hakka (Southern Suu-hsien Hakka).

[7] The italic words indicate the tone names in Chinese linguistics. T1 means the first tone, T2 the second, and so on.

[8] **Table 1: Tonal representations of Ssu-hsien and Hai-lu Hakka in Taiwan**

Dialects		*Yin-Ping*	*Yang-Ping*	*Shang*	*Yin-Chü*	*Yang-Chü*	*Yin-Ju*	*Yang-Ju*
Ssu-hsien	Yang (1957) (north)	24	11	31	55		22	55
	Chung (2004) (south/ Mei-nung)	33	11	31	55		31	55
Hai-lu	Yang (1957) Tao-yüan	53	55	13	31	22	55	32
	Lo (1990) Chu-tung	53	55	13	31	11	55	32
	Tu (1998) (Central Taiwan)	53	55	24	11	33	5	2

[9] The Tone No. used in this study is assigned by the author for the sack of convenience.

[10] The tonal representations used in this thesis are illustrated as follows.
"Tone1[33]" means the first tone with the T-scale of [33]. "*[am]52*" means the syllable *[am]* carrying the tonal scale [52].

[11] If the "tone" dominates the whole syllable, the TBU is the syllable itself, whereas the TBU is the "final" if only the part of compound vowel (the final) is dominated.

[12] The phonetic representations are used here because there are allophones of the long vowel as shown in the following rule.

/+tense, +vowel/→[-tense, +vowel]__{[p], [t], [k], [m], [n], [ŋ]}

There is an exception to this rule. That is, /u/ will remain as a tense vowel even when it is followed by [n].

Chapter 2 Methodology and Literature Review

In this Chapter, we will explicit the methodology used in this thesis, including the material used as the reading list, the subjects and recording procedure, the way we used to calculate the tonal scales, and the F0 measurement.

2.1 Word Inventories

In the present study, two kinds of word inventory were chosen as the stimuli. The first set was an inventory of monosyllabic words, and the second was an inventory of disyllabic words. Within monosyllabic words, two sets of words with different initials were chosen. The first was a voiceless aspirated stop initial *[kʰ-]*, and the other was a nasal initial *[m-]*. The two set of words are *[kʰjɛn]* and *[ma]*, carrying seven tones respectively. As has been mentioned in Section 1.2.2, the whole syllable would be measured in the present study. In order to minimize the effect of initial consonants on tones, we have selected syllables with voiceless initials in disyllabic words as possible as we could. The main reason why we decided to choose this kind of words is that voiceless initials outnumber voiced initials in Ta-pu Hakka—14 out of 20 consonants are voiceless. The two sets of inventory were shown in Appendix I and II.

For words in word-initial position (WI), there would be only six underlying tones, whereas there would be seven possible tones in the word-final position (WF) because

Tone7[35] in WI position was always the sandhi tone deriving from the underlying Tone1[33].[13] All the possible combinations were presented in Table 2.1. Among all the combinations, Tone1[33], Tone2[113], and Tone4[52] would be applied to tone sandhi rules when preceding particular tones, which was discussed in Section 1.2.4. In each possible combination, 4 items with similar syllable structure were chosen as possible as we could. To sum up, there were totally 168 items of disyllabic words. In Table 2.1, for example, Tone4[52] in WI position would turn Tone[55] in four of the combinations.

Table 2.1: Tonal combinations in disyllabic words (NA=Tone sandhi rules not applied)

Citation Tone	Sandhi Tone	Citation Tone	Sandhi Tone	Citation Tone	Sandhi Tone
5_5	NA	52_5	55_5	113_5	NA
5_52	NA	52_52	55_52	113_52	NA
5_113	NA	52_113	NA	113_113	33_113
5_2	NA	52_2	55_2	113_2	NA
5_31	NA	52_31	55_31	113_31	NA
5_33	NA	52_33	NA	113_33	NA
5_35	NA	52_35	NA	113_35	NA
2_5	NA	31_5	NA	33_5	NA
2_52	NA	31_52	NA	33_52	NA
2_113	NA	31_113	NA	33_113	35_113
2_2	NA	31_2	NA	33_2	35_2
2_31	NA	31_31	NA	33_31	35_31
2_33	NA	31_33	NA	33_33	NA
2_35	NA	31_35	NA	33_35	NA
6*7=42 (combinations); 4 (items)*42=168 (items)					

2.2 Calculation of T-scales via Two Versions

In the present study, two methods of calculating T-scales were adopted. The first methodology was the formulae reconstructed and postulated by Fon and Chiang (1999). They postulated this set of formulae base on Chao's analogy of tonal scales to musical notes as the five reference points(Chao, 1968). Chang (1995) and Huang (2003), on the other hand, adopted Shi's (1990) logarithmic function to transform the measured pitch range of a speaker into five exponential scales. As a comparison, both Fon and Chiang's formulae and Shi's function would be adopted to calculate the T-scales of Ta-pu Hakka tones.

2.2.1 Fon and Chiang's Version

The tonal representations of Mandarin had never been challenged until Fon and Chiang (1999) tried to find out what tones in Mandarin were really like via acoustic study. They adopted monosyllabic words and tri-syllabic words in their acoustic study and tried to find out if tonal representations would be different when acoustic data were taken into consideration. After comparing different versions of calculating T-scales by different scholars, they suggested that the tonal representations in Taiwan Mandarin should be revised. They also suggested that Chao's second version which postulated the exponential relation might only be an *ad hoc* device for Mandarin because his system

(Chao, 1956) was basically equi-exponential. They further suggested that Chao's second version might be tailor-made for Mandarin and further cross-linguistic studies concerning the relationship between Chao's system and tone languages are required in order to test if Chao's second version is applicable for other tone languages.

In Chao's second version (1968), he chose five musical notes with unequal interval as the reference points: $^{\#}$F, G, ^{b}B, C, and D. The scale of Chao's second version was postulated and illustrated by Fon and Chiang in Figure 2.1.

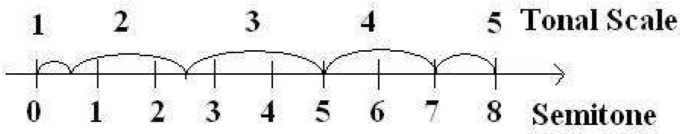


Figure 2.1: A tonal scale-semitone correlation of Chao's second version. (Fon & Chiang, 1999, p. 18)

They reduced the range of Scale 1 from one semitone to 0.5 semitone. As for Scale 3, the range was expanded from two semitones to 2.5. They then postulated a set of formulae to calculate the T-scales of exponential correlation. The formulae in fact included four equations, presented here again from (7) to (10). Function (6) was the preliminary step of converting pitch value obtained in Hz into semitone.

(6) Hz to Semitone conversion: (N)=39.86*log10(fi / fmin)[14]

(7) *Tone#* = N/**2**+1 (if N≧**3**)

(8) *Tone#* = Tone3 (if **2.5**≦N<**3**)

(9) *Tone#* = Tone2 (if **0.5**≦N<**2.5**)

(10) *Tone#* = Tone1 (if 0≦N<**0.5**)

After converting Hz to semitone, the obtained semitone value was then referred as N. Then, one of the equations, (7) to (10), was applied according to the obtained N value. For example, when the pitch difference in semitone (N) between two measured points was larger than or equals to 3 semitones, equation (7) would be applied and the tonal scale will be obtained. Table 2.2 showed the result of Fon and Chiang's revised tonal representations compared with Chao's original notations (1930).

Table 2.2: Tonal representations of Mandarin revised by Fon and Chiang

	Tone1	Tone2	Tone3	Tone4
Chao (1930) Phonological Representations	55	35	214	51
	High-level	Rising	Concave	Falling
Fon and Chiang (1999) Phonological Representations	**44**	**323**	**312**	**42**
	High-level	Concave (*Higher* offset)	Concave (*Lower* offset)	Falling
				

The result of Fon and Chiang's study suggested that the T-scales of the four tones should be revised as [44], [323], [312], and [42]. Tone2, instead of a rising tone, was in fact a concave tone according to the phonetic realizations. Traditionally, Tone2 used to be regarded as a rising tone by Chao and its T-scale was denoted as [35]. However, the result of Fon and Chiang's study indicated that there was a dipping characteristic (a phonetic fall) in the middle of this tone. As a result, they suggested that the T-scale of Tone2 should be revised as [323]. As for Tone3, Chao's (1930) notation [214] and Fon and Chiang's (1999) revision [312] both showed that it was a concave (dipping) tone. As a result, according to the revised tonal representations in Mandarin, both Tone2 and Tone3 were suggested to be concave tones. In our present study, we will try to find out if a level tone or a rising tone will also exhibit this kind of dipping characteristic in the middle of a syllable.

Besides the different phonetic realizations in Tone2, they also found that Tone1[44] did not reach the top scale of [5]. As a result, they suggested that a four-scaled representation system was sufficient for Taiwan Mandarin. They also found that tonal height in Taiwan Mandarin was compacted to lower register.

However, one possible undesirable problem might occur in Fon and Chiang's study. We would wonder why the revised T-scales never reached scale 5. In their study, the average pitch range of the sole speaker was about 5.5 to 6.8 semitones, but the formulae they postulated in their study were based on a pitch range of **"eight"** semitones. That is, the actual pitch range of their collected data had not reached **eight** but they had actually applied the data into those equations, the obtained T-scales would certainly be compacted into the lower register. Their explanation was that Taiwan Mandarin was considerably influenced by Taiwanese, which belonged to the southern dialects and was noted for its low pitch register (Lin & Repp, 1989). However, we still believed that the reason why the T-scale did not reach scale 5 was that the formulae should have been modified based on the average pitch range of all the speakers recruited in a study. On the other hand, we also wondered why the tones of a language like Taiwanese, which has more contrastive tones, would have been compacted to a lower register. Would it not be difficult for Taiwanese speakers to distinguish one tone from another?

Therefore, when adopting Fon and Chiang's version of formulae, we would adjust the four equations according to the average pitch range of our six informnats. For example, if the pitch range of all the data collected in our study is 12 semitones, we will multiply each number in Equation (7) to (10) 1.5 times in order to avoid compressing the T-scales into lower registers. Furthermore, by adopting Fon and Chiang's formulae, we will try to investigate if Chao's second version of non-linear correlation of tones is applicable to tones in Ta-pu Hakka.

2.2.2 Shi's Logarithmic Function

Two other acoustic studies that investigated the interaction between tonal representations and phonetic realizations were Chang (1995) and Huang (2003), which have been discussed briefly in Chapter 1. They both adopted the logarithmic function proposed by Shi (1990), which was shown in (11).

(11) T-scale= $5 * (\log\chi - \log \boldsymbol{b})/(\log \boldsymbol{a} - \log \boldsymbol{b})$
("***a***" represents the maximum F0 measured, "***b***" the minimum F0, and "**χ**" the F0 of the target point, i.e. the F0 of BP, EP, Peak, and Valley)

Shi's logarithmic function converted the pitch differences into an exponential correlation because it was logarithmic. This exponential correlation could also be seen in Fon and Chiang's postulated formulae.

The major difference between the two versions was that the largest pitch span in Fon and Chiang's (1999) version was in scale 3, and the span decreases toward the two ends. On the other hand, the largest pitch span in Shi's version would be in scale 5, and the span decreases from Scale 5 to Scale 1. Figure 2.2 showed an illustration of the correlation between T-scale and Hz. The data in this figure were obtained from monosyllabic words in our present study.

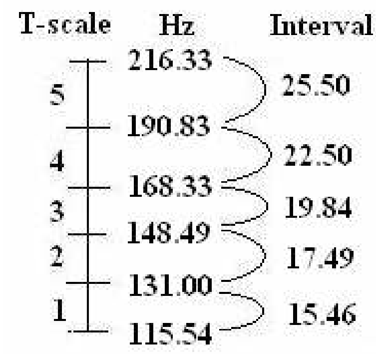


Figure 2.2: An illustration of Shi's function

As can be seen from this figure, the interval of each scale was enlarged as the scale was getting higher and higher. Therefore, Scale 5 had a larger interval than all the other scales, which was different from Fon and Chiang's version. Nevertheless, the obtained T-scales would also exhibit a kind of exponential correlation because of the essence of the logarithmic function.

2.3 Effects of Tonal Coarticulation

The second research question in the present study is with regard to the effects of tonal coarticulation. In Section 2.3.1, we will first discuss the tonal variations when tones are positioned in different prosodic positions—WI or WF positions in this study. In Section 2.3.2, we will discuss the tonal variations when tones are in a compatible or a conflicting context. Afterward, we will discuss how tones might be affected by their neighboring tones in Section 2.3.3. In Section 2.3.4, we will briefly introduce the Target Approximation model (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001).

2.3.1 Prosodic Contextual Effect

With regard to the contextual effect on tonal coarticulation, Peng (1997) conducted an experiment and found that prosodic contexts, which referred to the position a tone was located in a multi-syllabic word, had a greater effect on Taiwanese tones than tonal contexts. In Peng's (1997) study, the prosodic contexts were referred to phrase-initial, phrase-medial, phrase-final and utterance-final positions. In that study, F0 range was substantially shifted by prosodic position in some conditions: final-lowering of F0 and final lengthening were found in utterance-final and, to a lesser extent, in phrase-final position. Final-lowering and final-lengthening of F0 were also found in our study, but these phenomena only existed in some tones (see Section 4.3.1 for details).

2.3.2 Tonal Contextual Effect

Xu (1994) found that tonal contexts could be categorized into two domains: a compatible and a conflicting context.

According to Xu's (1994) definition:

> A compatible context is where the adjacent phonetic units have identical or similar values along the phonetic dimension, while a conflicting context is a context where the adjacent phonetic units have very different values. (p. 2240)

Xu (1994 & 1997) and Wang & Seneff (2000) found that the slope of a falling tone or a rising tone was steeper in a compatible context, while it became smaller when in a conflicting context. Their claims were based on the findings in Mandarin Chinese.

As for tones in Ta-pu Hakka, there are seven citation tones, and hence more possible disyllabic-word combinations are to be found. When categorizing these tonal combinations in disyllabic words, we have found that there is another possible context. That is, when a rising tone followed by a falling tone, or when a falling tone followed by a rising tone, the two kinds of tonal combinations will form a compatible context, not in adjacent tonal values, but in the adjacent tonal contours. Therefore, we will categorize the tonal combinations in Ta-pu Hakka into three categories: a compatible context, a conflicting context, and a contour compatible context.

2.3.3 Adjacent Tone Effect

In the study of how adjacent or neighboring tones interacted with each other in Mandarin, onsets and offsets of tones (Wang & Seneff, 2000) and average F0 (Shen, 1990) were found to be affected by adjacent tones. Wang and Seneff (2000) found that F0 of tones were influenced by the onset F0 of the following tones, indicating an anticipatory effect. The lowest onset value (Tone3[213]) would raised the average F0 of its preceding tones, and the highest onset value, especially of Tone1[55] would lower the average F0 of its preceding tones. The result in their study indicated an anticipatory dissimilation effect, which could also be found in our study of Ta-pu Hakka. From the opposite direction, which indicated a carryover effect, they found that tones with high offset value (Tone1[55] and Tone2[35]) would raise the onset value of the following tones, which was a kind of assimilation effect, and carryover assimilation was also found in our study. Another kind of carryover assimilation was found in Tone3[214] in Mandarin. They found that the falling slope of Tone3[214] was steeper when preceded by tones with high onset values.

Besides the influence of onset and offset pitch height, Shen (1990) found that the average F0 of tonal contours was also affected by neighboring tones. The average F0 of tones following high-offset tones was higher than that of tones following low-offset tones. In Shen’s study, the tonal coarticulation effect was also a kind of carryover assimilation. For comparison, we will also look into how the onset and offset pitch values of adjacent tones will influence tonal coarticulation in Ta-pu Hakka (for details, see Section 4.5).

2.3.4 Xu's Target Approximation model

In Xu's latest studies (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001), he has proposed a Target Approximation model to explain the phenomena of tonal variations in Mandarin. This TA model "simulates the generation of F0 contours as a process of asymptotically approximating underlying pitch targets that are associated with individual tones via language-specific rules" (Xu, 2004, in abstract). By applying the TA model to the phenomena of different tonal variation patterns, Xu divided the tonal variations in Mandarin into two types: (1) variations due to target alternation; and (2) variations due to articulatory implementation.

Xu (2004) defined the two types of variations as follows:

> ***Target alternation*** occurs in cases where the pitch target of a tone is presumably changed before being implemented in articulation. ***Implementational variations*** are cases where tonal targets remain the same, but the acoustic realization of the targets is varied due to their implementation in different

tonal contexts and/or with different amount of articulation effort. (p. 784)

We considered that "***target alternation***" in TA model indicates the phonological tonal variations due to tone sandhi, whereas "***implementational variations***" referred to those due to coarticulation. The basic operation of the TA model was schematically sketched in Figure 2.3.

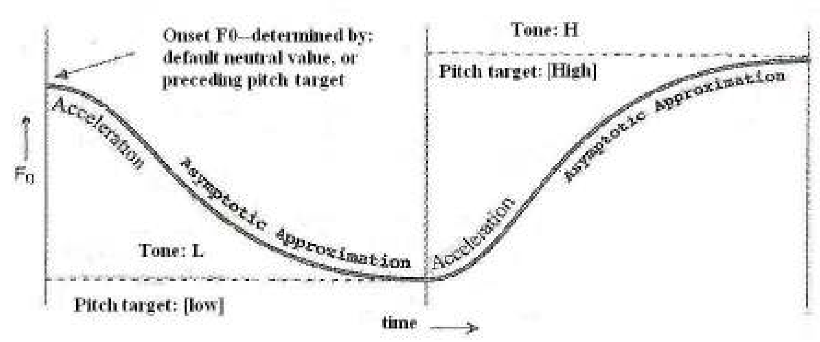


Figure 2.3: A schematic sketch of the Target Approximation model. The vertical lines represent syllable boundaries. The dashed lines represent underlying pitch targets. The thick curve represents the F0 contour that results from articulatory implementation of the pitch targets (Xu , 2004, p. 771, Figure 6).[15]

According to Xu (2004), "at the core of the model is the assumption that phonological tone categories are not directly mapped onto surface phonetic patterns; rather, each tone is associated with an ideal pitch target that is articulatorily operable" (p. 771). The pitch targets mentioned were divided into static pitch targets and dynamic pitch targets. The former referred to [high], [mid] or [low], and the later referred to [fall] or [rise].

Xu has found that tonal coarticulation can be better explained by the notion of TA model. "According to the TA model, a tone simply starts from wherever the previous tone ends and approaches its underlying target over the duration of the tone-bearing syllable. This has been recently found to occur in Cantonese as well" (Y. Xu, personal communication, June 21, 2007). Wong (2006) adopted TA model to investigate the tonal variations in Cantonese. By applying this model, Wong (2006) pointed out that the results of his study showed "directional asymmetries in terms of nature and magnitude of contextual tonal variations" (Conclusions, para. 1). As a result, in the present study, we will try to see if this TA model can help explain the tonal variations in Ta-pu Hakka. By doing so, we hope to shed a light in the study of tonal coarticulation in a language other than Mandarin.

2.4 Subjects and Recording

Ta-pu Hakka is spoken mainly in Tai-chung County in Taiwan, especially in Tung-shih, Hsin-she and Shih-kang. Therefore, the six informants who participated in this study all live in Tung-shih, the major township where most Ta-pu Hakka speakers reside. Three of our informants were male, and the others were female, of course, and their average age was 60 years old. All of them speak Hakka and Mandarin in their daily life, and they also speak Taiwanese when they communicate with Taiwanese speakers. The details of our informants' background were shown in Table 2.3. The reason why we chose those informants aged sixties was that all of them were educated and not illiterate so that they could easily understand the instruction and they were able to read the experimental items printed either in Roman letters or in Chinese orthography. Furthermore, older people have better competence and performance in speaking Ta-pu Hakka.

Table 2.3: Informants' background

Name	Gender	Age (yr)	Place of residence	Languages spoken
Hsieh Ai-chu	Female_1	56	Tung-shih	Hakka Mandarin Taiwanese[16]
Ch`in Hsiu-chin	Female_2	60		
Huang Shu-mei	Female_3	60		
Liu Ch`ao-chiang	Male_1	58		
Liu Sung-chün	Male_2	61		
Chiang T`ai-hung	Male_3	65		
mean=60 years old				

Our six informants all live in Tung-shih, so we conducted the recording in the informants' residences for their convenience. The recording was conducted in a quiet room with curtains to avoid echoing effect. We used a SONY Digital Audio Tape (DAT) Recorder to record the utterances. While recording, a SONY condenser microphone was positioned 10 to 20 centimeters away from the informant's mouth adjusted according to the volume of each individual. And each informant was asked to read each item 3 times with about 0.5-second intervals between repetitions. Only the clearest utterance would be selected because sometimes creaky voice would appear in the recorded data and the pitch value was not able to be fetched. This might be due to the age effect of our informants because older people might have creakier voice quality.

When the three utterances were all very clear, we would choose the middle one in order to minimize initial-raising or final-lowering effect. Each item was printed on a piece of 5*3-inch paper. The set of monosyllabic words was shown first, and then that of the disyllabic words. Both sets were randomly arranged. The recording procedure for each informant lasted about half an hour, so their performances would not be influenced by the effect of fatigue.

2.5 Parameters Measurement

After finishing all the recording in our informants' residences, the recorded sound was digitized into Kay Elemetrics CSL 4400 at a 44100-Hz sampling rate in the Phonetics Lab in Graduate Institute of Linguistics in National Taiwan University. Afterwards, the data were analyzed by using the software Praat. The version of Praat used in this study was 4.3.27.

Because we tried to measure the average pitch with different kinds of onset consonants, we thus chose *[kʰjɛn]* and *[ma]* to make up the tonal paradigms in monosyllabic words as have been mentioned in 2.1. For syllable *[kʰjɛn]*, only the appeared pitch contour will be measured, while for syllable *[ma]*, the measurement will start at the onset of the initial.

As has been discussed in Section 1.2.2, the whole syllable was included in the measured parameters in this study. Thus, for all the selected items, the voiceless initial consonants will be truncated, but the voiced initials will be included in the measurement. In our study, the only three voiced initials chosen in some of the disyllabic words were *[m-], [ʒ-],* and *[v]*.

As for the coda consonants, F0 of the three nasal consonants, *[-m], [-n],* or *[-ŋ]*, was included in the measurements because sonorants in coda were considered to bear tones. On the other hand, F0 of the stop codas, *[-p], [-t],* or *[-k]*, which constituted checked tones, was excluded since there would be no pitch value being able to be fetched. As for the detailed discussion of parameters to be measured in this study, we will make an explicit definition in Section 2.6.

Figure 2.4 and 2.5 showed how we determined the boundary in a syllable. The beginning point (BP) and ending point (EP) were marked manually, but the minimum pitch (Valley) and the maximum pitch (Peak) were fetched automatically by using Praat script.[17] The word *[kʰjɛn]* in Figure 2.4 had a voiceless aspirated initial, which generated no pitch except for the transition point, so the measurement included the medial *[j]*, the vowel *[ɛ]* and the coda *[n]*. On the other hand, the word *[ma]* in Figure 2.5 was a syllable comprising a nasal initial *[m]* and a vowel *[a]*. The initial *[m]* was included because we wanted to fetch the visible pitch value in a syllable with a voiced initial.

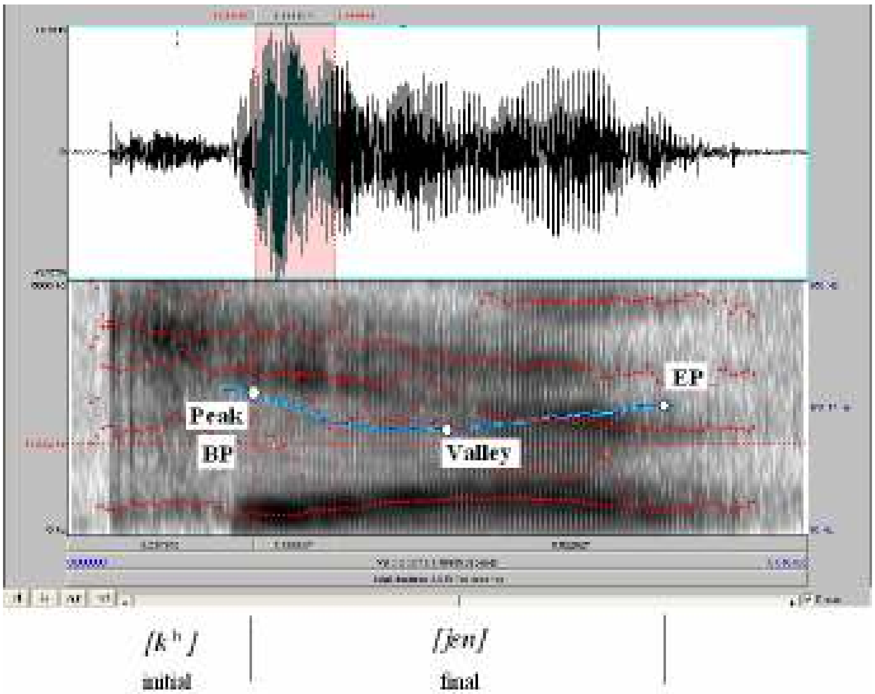


Figure 2.4: A demonstration of marking the boundary of word *[kʰjɛn]113* "power" on Praat. (Peak=BP in this syllable)

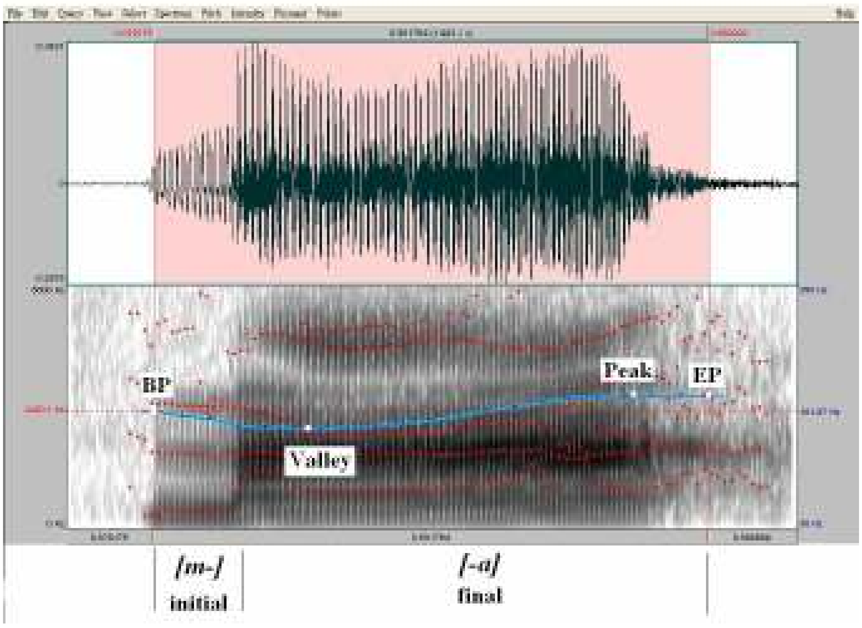


Figure 2.5: A demonstration of marking the boundary of word *[ma]113* "be numb" on Praat.

2.6 Definitions of Various Parameters

We referred to Chiang & Chiang's study of Saisiyat in 2006 when deciding the parameters to be measured in this study. The parameters measured in their study are confined to the rhyme of the syllable, whereas the "whole syllable" with visible pitch would be included in our study. Most of the parameters measured in this study were the same as their study with only some modifications in order to meet our need. Therefore, the modified parameters to be measured in our study were listed as follows.

F0 height (Hz): at onset (BP), offset (EP), peak, and valley
Duration (Sec.): $t_{offset} - t_{onset}$
F0 slope: $(F0_{offset} - F0_{onset})/(t_{offset} - t_{onset})$
F0 valley alignment (%): $(t_{valley} - t_{onset})/(t_{offset} - t_{onset})*100$[18]
F0 peak alignment (%): $(t_{peak} - t_{onset})/(t_{offset} - t_{onset})*100$
Intensity (dB): at onset, offset, peak, valley, and the average intensity

F0 height was measured at four points in each syllable: onset, offset, peak, and valley. We would not measure the fundamental frequency by normalizing the raw curves as to duration because we wanted to present the original pitch contour so that the realities of the tones in Ta-pu Hakka could be easily seen, just like the way Chiang and Chiang (2006) did in investigating Saisiyat as a pitch accent language. By normalizing the measured pitch as to duration, we might overlook the importance of duration, which plays as a key to distinguish checked tones from unchecked tones in Ta-pu Hakka.

In Chiang & Chiang's study (2006), F0 slope was measured as the rate of movement from the peak to the valley. However, F0 slope in this study was measured as the rate of movement from the starting point to the ending point of the syllable. We calculated the F0 slope as F0 offset-onset difference divided by duration in millisecond of the syllable. If an F0 slope value is positive, the pitch contour is assumed to be rising. On the contrary, if the F0 slope value is negative, the pitch contour is regarded as falling. As for F0 valley alignment, we calculated the temporal position in which the pitch valley was located within a syllable of Tone2[113], Tone7[35] and Tone1[33] (OTR). This was calculated by using the formula, $(t_{valley} - t_{onset})/(t_{offset} - t_{onset})*100$. By calculating the temporal position of the pitch valley occurrence, we are able to explore the dipping characteristic in a level or rising tone. If there is a dipping somewhere in the syllable, and if the falling contour is steep enough to reach a lower scale, these tones are considered as concave tones according to their phonetic features. As for falling tones, we calculated the temporal position of the pitch peak occurrence in order to investigate if there is peak delay in falling tones, which will also be discussed in Chapter 4.[19]

As for the measurement of intensity, Huang (2003) found that intensity in Mei-nung Ssu-hsien Hakka was considered an assistant acoustic cue of distinguishing checked tones from unchecked tones. For comparing tonal characteristics in Hakka subdialects, we also measured the intensity of the four points, BP, EP, the valley and the peak in monosyllabic words. By doing so, we were able to explore the role that intensity would play in Ta-pu Hakka.

To sum up, the parameters being measured functioned differently in our two research questions. For verifying tonal representations of falling tones and checked tones, the revised tonal representations were given according to the T-scales obtained from the two points, BP and EP, in both monosyllabic and disyllabic words. For level or rising tones, we took the pitch value of the valley into consideration and then decided if these tones were concave tones. As for investigating tonal coarticulation, the most important parameters were BP, EP, mean F0, duration, slope and F0 valley alignment. BP and EP indicated the onset and offset pitch value. The slope and F0 valley alignment would show the change of pitch contour. Since all the words in our reading list were used in order to answer the two research questions, we measured all the parameters needed in both cases.

Notes:

[13] Tone7[35] were considered as a kind of diminutive suffix of Tone1[33] in some particular morphological contexts (Chiang, J.-L, 1996, 2002; Chiang, M.-H., 1998a & b; Tsao & Yeh, 2005).

[14] Hz to Semitone conversion (Baken & Orlikoff, 2000):

Semitone=39.86*$\log_{10}(f_i / f_{min})$ (i=the F0 of the target pitch; min=the minimum F0 measured within a certain group)

This function has been existed long but has been discussed thoroughly in Baken and Orlikoff. Therefore, we acknowledge the source of this function to Baken and Orlikoff (2000).

[15] This figure is scanned and copied from (Xu 2004, p. 771, Figure 6) with the permission granted by Xu.

[16] Since there are also a lot of Taiwanese speakers living in Tung-shih, all of them can also speak fluent Taiwanese.

[17] The Praat script used to fetch pitch was developed by I Chang-Liao, an alumna of Graduate Institute of Linguistics, National Taiwan University. We are very grateful for her being so generous to share this script with us. However, we will not put the script in the appendix because the copyright policy.

[18] In Chiang and Chiang (2006), what they measured is the F0 “peak” alignment instead of the F0 “valley” alignment because they were trying to investigate whether Saisiyat is a pitch-accent language. Thus, they only calculated the F0 peak alignment.

[19] For detailed discussion of peak delay, refer to Xu (2004).

Chapter 3 Tonal Representations Revised via Acoustic Data

In this Chapter, we adopted Fon and Chiang's (1999) formulae and Shi's (1990) logarithmic function to verify the tonal scales (T-scales) of tonal representations in Ta-pu Hakka. By using monosyllabic words, we were able to verify the T-scales of citation tones, and via disyllabic words, we were able to explore the T-scales of sandhi tones along with the T-scales of tones in WI and WF positions.

3.1 Tonal Representations Revised via Monosyllabic Words

In this section, we verified the tonal representations by using the acoustic data obtained from the 14 monosyllabic words produced by our six informants. As has been mentioned in 2.2, we adopted two kinds of calculating methods to verify the tonal scales in Ta-pu Hakka. When adopting Fon and Chiang's (1999) formulae, we first fetched all the pitch height of the measured points in Hz, and then the F0 values in Hz were converted into the semitone value (Section 3.1.1). As for Shi's (1990) logarithmic function, the F0 data in Hz did no need to be converted into semitone (Section 3.1.2). In Section 3.1.3, we compared the revised citation tones via the two sets of formulae and tried to assume which rationale was more suitable for verifying tonal representations in Ta-pu Hakka.

In the present study, we used the Praat script to fetch all the parameters being measured in our study, and then we manually checked all the missing values. The means and standard deviations of F0 of the four measured points, BP, EP, Peak, and Valley were shown in Table 3.1. In Table 3.1, the mean was obtained from the six informants' utterance of monosyllabic words.

In the present study, we first gathered all the raw data of the four measured points, and then we calculated the average pitch value of each point in each tone. In the present study, we used the average pitch value of all the raw data obtained from our six informants when we tried to verify the T-scale of the group, namely, the six informants.

In Table 3.1, the average minimum F0 of all the measured pitch value was 115.54 Hz (SD=39.56 Hz). Note that the large standard deviations in all the measured values were due to gender difference. The average pitch height of females was much higher than male, $t(76)=-14.109$, $p<.001$. The average pitch height of females was 206.06 Hz, whereas that of males was 122.09 Hz. Since we have chosen three males and three females, the differences between the two genders would be minimized when we adopted the average pitch value of the whole six-person group. As a result, the average pitch value of the four measured points would show the average performance of each tone.

Table 3.1: Mean of the measured parameters of tones in monosyllabic words produced by the six informants (SD=standard deviation, and the OTR indicates the tonal scales used in *Ta-pu Hakka Dictionary*)

OTR	No. of cases	BP_Hz (SD)	EP_Hz (SD)	Peak_Hz (SD)	Valley_Hz (SD)
33	12	165.67	152.17	169.51	148.49
		(49.48)	(43.11)	(50.02)	(43.53)
35	12	158.21	186.36	191.96	148.08
		(49.87)	(57.17)	(60.23)	(43.30)
31	6[20]	173.40	116.51	176.54	115.54
		(53.07)	(40.63)	(55.43)	(39.56)
52	12	209.23	147.49	216.33	143.43
		(61.61)	(53.18)	(63.59)	(47.54)
113	12	149.21	147.06	157.45	116.92
		(46.33)	(48.46)	(48.85)	(37.67)
2	12	168.35	148.60	172.16	148.34
		(52.92)	(43.43)	(54.27)	(43.55)
5	12	190.78	185.09	197.06	179.52
		(51.13)	(49.30)	(51.75)	(46.61)

By using the average pitch values of the four measured points, we would be able to calculate the T-scales of Ta-pu Hakka tones, and the calculation procedure and the results would be presented in Section 3.1.1 to 3.1.4.

3.1.1 Fon and Chiang's Formulae

Function (12) was applied to calculate the interval in Semitone (ST) between the beginning point of Tone 113-OTR and the minimum pitch of all the data, which is 115.52 Hz. The result was shown in (13):

(12) Hz to Semitone conversion: (N)=39.86*log10(fi / fmin)
(13) N(semitone)=39.86* $\log_{10}$(149.21/115.54)=3.24

The result indicates that there was a 3.3-semitone difference between BP of Tone 113 and the average minimum pitch of all. Thus, by applying function (12) to all the four measured points, BP, EP, peak, and valley, we got the result of semitone differences in Table 3.2. Each N value indicated the differences in semitone between the average minimum pitch and the pitch of target point.

Table 3.2: N value in semitone of the four measured points. (N=ST=semitone; OTR=original tonal representations in *Ta-pu Hakka Dictionary*) (*min=115.52 Hz, the average of minimum pitch obtained from all the utterances)

OTR		BP-min* (ST)	EP-min (ST)	Peak-min (ST)	Valley-min (ST)
T1	33	6.24	4.77	6.64	4.34
T2	113	4.43	4.18	5.36	0.21
T3	31	7.03	0.14	7.34	0.00
T4	52	10.28	4.23	**10.86**	3.74
T5	2	6.52	4.36	6.90	4.33
T6	5	8.68	8.16	9.24	7.63
T7	35	5.44	8.28	8.79	4.30

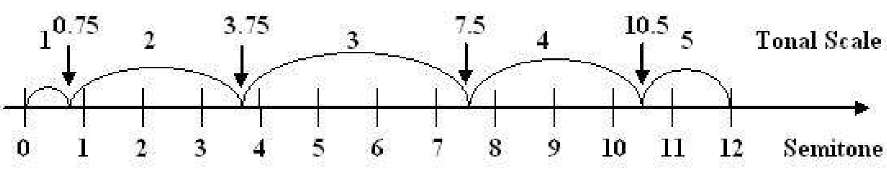
As we can see from Table 3.2, the pitch ceiling was 10.86, indicating that the pitch range was about 11 semitones. However, after we looked into each speaker's data, the pitch ranges of the six speakers were 15, 13, 13, 11, 11, and 10, respectively, and the average pitch range was 12 semitones. Therefore, we postulated that the average pitch range in Ta-pu Hakka accent among different speakers would be close to 12 semitones. The original equations of the pitch range of eight semitones used in Fon and Chiang's

(1999) study were now presented again in (14) to (17) for direct comparison with our revised equations based on 12 semitones.

(14) *Tone#* = N/2+1 (if N≧3)
(15) *Tone#* = Tone3 (if 2.5≦N<3)
(16) *Tone#* = Tone2 (if 0.5≦N<2.5)
(17) *Tone#* = Tone1 (if 0≦N<0.5)

In our study, there are seven tones in Hakka, so the pitch range would be expected to be larger than that of Mandarin (Maddieson, 1978). That the result of the pitch range in our data was "12" supported this claim. In the present study, we further reconstructed the formulae used by Fon and Chiang. The enlarged pitch range of 12 semitones meant that we had to multiply each value in Fon and Chiang's (1999) equations by 1.5 times. The reconstructed formulae were shown from (18) to (21). And the correlation between the tonal scale and the semitone of an enlarged pitch range of 12 and the decision points within each scale were illustrated in Figure 3.1.

Our version of reconstructed formulae (pitch range=12 semitones)
(18) *Tone#* = N/**3**+1 (if N≧**4.5**)
(19) *Tone#* = Tone3 (if **3.75**≦N<**4.5**)
(20) *Tone#* = Tone2 (if **0.75**≦N<**3.75**)
(21) *Tone#* = Tone1 (if 0≦N<**0.75**)



0.0≤Scale1<1.5
1.5≤Scale2<2.5
2.5≤Scale3<3.5
3.5≤Scale4<4.5
4.5≤Scale5≤5.0

Figure 3.1: A tonal scale-semitone correlation of an enlarged pitch range of 12

After reconstructing the formulae, we then applied Equation (18) to (21) to calculate the T-scales. When the N value was larger than or equal to 3.75 and smaller than 4.5, the tonal scale would be 3 by applying equation (19). When N was larger than or equal to 0.75 and smaller than 3.75, the tonal scale would be 2. Finally, when N was between 0 and 0.75 or equals to 0, the tonal scale would be designated 1. Finally, when N was larger than or equal to 4.5, equation (18) would be applied to calculate the T-scale. After doing all the calculations one by one, the revised T-sacles were shown in Table 3.3. When the obtained T-scale was larger than The seven citation tones were revised as follows: T1 as [33], T2 as [313], T3 as [31], T4 as [53], T5 as [3], T6 as [4], and T7 as [34]. The discussion of the results will be in Section 3.1.3.

Table 3.3: The revised T-scales and their corresponding N values. (OTR=original tonal representations in *Ta-pu Hakka Dictionary*; RTR=revised tonal representations)

OTR		BP		EP		Peak		Valley		**RTR**
		N	T-scale	N	T-scale	N	T-scale	N	T-scale	
T1	33	6.24	**3.27**	4.77	**2.73**	6.64	**3.41**	4.34	**2.58**	**33**
T2	113	4.43	**2.61**	4.18	**2.52**	5.36	**2.95**	0.21	**1.00**	**313**
T3	31	7.03	**3.34**	0.14	**1.00**	7.34	**3.67**	0.00	**1.00**	**31**
T4	52	10.28	**4.74**	4.23	**2.54**	10.86	**4.95**	3.74	**3.00**	**53**
T5	2	6.52	**3.37**	4.36	**2.58**	6.90	**3.51**	4.33	**2.57**	**3**
T6	5	8.68	**4.16**	8.16	**3.97**	9.24	**4.36**	7.63	**3.77**	**4**
T7	35	5.44	**2.98**	8.28	**4.01**	8.79	**4.20**	4.30	**2.56**	**34**

3.1.2 Shi's Logarithmic Function

Besides using Fon and Chiang's equations, we also tried Shi's logarithmic function. Shi's logarithmic function was used to divide the average pitch range of the six informants into a five-scaled system. The logarithmic value of fundamental frequency was used because a logarithmic correlation existed between human's perception of tones and the fundamental frequency of pitch value (Xu et al., 2006). Shi's function was illustrated here again in (22).

(22) T-scale= 5 ∗ (logχ-log***b***)/(log***a***-log***b***)
("***a***" represents the maximum F0 measured, "***b***" the minimum F0, and "χ" the F0 of the target point, i.e. the F0 of BP, EP, peak, and valley)

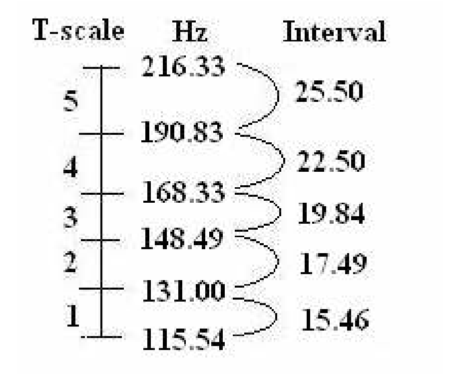
In the present study, the ***a*** and ***b*** represented the average maximum and minimum pitch of the six informants respectively. Thus, according to the data shown in Table 3.1, ***a*** was 216.33 Hz, and ***b*** was 115.54 Hz. For example, the pitch value of BP of Tone2[113] was 149.21 Hz, and the obtained T-scale via (22) was 2.04. An example of calculation was shown in (23).

(23) T-scale= 5 ∗ (logχ-log***b***)/(log***a***-log***b***)
= 5 ∗ (log**149.21**-log115.54)/(log216.33-log115.54)
=2.04

All the obtained T-scales of the four measured points were shown in Table 3.4. In the present study, the T-scale of a tone was assigned mainly according to the T-scales on the two edges of the syllable, namely BP and EP. As for rising tones, we assumed that there would be a phonetic fall somewhere in the syllable (Fon and Chiang, 1999). Thus, we would take the T-scale of the valley into consideration. For example, the T-scale of the valley of Tone2 was 0.09, which was assigned as Scale 1. The revised T-scales and the decision ranges within each scale were illustrated in Figure 3.2.

Table 3.4: Average F0 in Hz of the four measured points and their corresponding T-scales via Shi's function. (The standard deviation of the four measured points were omitted here for easy illustration—referring to Table 3.1)

OTR		Hz				T-scale				RTR
		BP_F0	EP_F0	Peak_F0	Valley_F0	BP	EP	Peak	Valley	
T1	33	165.67	152.17	169.51	148.49	2.87	2.20	3.06	2.00	33
T2	113	149.21	147.06	157.45	116.92	2.04	1.92	2.47	0.09	312
T3	31	173.40	116.51	176.54	115.54	3.24	0.07	3.38	0.00	41
T4	52	209.23	147.49	216.33	143.43	4.73	1.95	5.00	1.72	52
T5	2	168.35	148.60	172.16	148.34	3.00	2.01	3.18	1.99	43
T6	5	190.78	185.09	197.06	179.52	4.00	3.76	4.26	3.51	54
T7	35	158.21	186.36	191.96	148.08	2.51	3.81	4.05	1.98	324



4.0≤Scale 5≤5.0
3.0≤Scale 4<4.0
2.0≤Scale 3<3.0
1.0≤Scale 2<2.0
0.0≤Scale 1<1.0

Figure 3.2: Revised T-scales via Shi's logarithmic function and the decision ranges within each scale

Via Shi's logarithmic function, the seven citation tones were suggested to be revised as the follows: Tone1 as [33], Tone2 as [312], Tone3 as [41], Tone4 as [52], Tone5 as [43], Tone6 as [54], and Tone7 as [324].

As can be seen from Figure 3.2, the governing pitch span was 15.46 Hz in Scale 1, 17.49 Hz in Scale 2, 19.84 Hz in Scale 3, 22.50 Hz in scale 4, and 25.50 Hz in Scale 5. The span of each scale was becoming larger and larger as the pitch was getting higher, indicating a non-linear correlation. However, the non-linear correlation was not quite the same as that of Fon and Chiang's formulae demonstrated in Figure 3.1. In Figure 3.1, Scale 3 had the widest governing pitch span, 3.75 semitones, and the span narrowed down toward the two ends. The span was 3 semitones in Scale 2, 0.75 semitones in Scale 1, 3 semitones in Scale 4, and 1.5 semitones in Scale 5. The different non-linear correlation shown via the two kinds of calculating methods would be discussed in Section 3.1.3.

3.1.3 Discussion of the Two Revised T-scales

The revised RTRs via formulae reconstructed based on Fon and Chiang's version and Shi's logarithmic function are shown in Table 3.5. Table 3.6 shows the prescriptive and descriptive tonal tonal system of the ORT and the RTR via two versions. The RTRs via the two versions show some discrepancy, but Table 3.6 shows that revised T-scales in the descriptive tonal system are more equally distributed along the five scales, within which Scale 4 never appears in the OTR.

Table 3.5: Comparison of the revised tonal representations (RTR) with the original tonal representations (OTR) adopted in *Ta-pu Hakka Dictionary* (Shü et al., 2005)

ORT		RTR	
Tone No.	T-scale	Via Fon & Chiang Version	Via Shi's Version
Tone1	33	**33**	**33**
Tone2	113	**313**	**312**
Tone3	31	**31**	**41**
Tone4	52	**53**	**52**
Tone5	2	**3**	**43**
Tone6	5	**4**	**54**
Tone7	35	**34**	**324**

Table 3.6: Prescriptive vs. descriptive tonal system of Ta-pu Hakka

T-scales	Phonological (Prescriptive)	Phonetic(Descriptive)	
	OTR (***Ta-pu Hakka Dictionary***)	Via Fon & Chiang's Version	Via Shi's Version
5	***	*	**
4		**	****
3	*****	*****	*****
2	**	**	***
1	***	**	**

Among the seven tones, only the T-scales of Tone1 are the same—[33]. The revised T-scale of Tone7 via Shi's function shows a phonetic fall in the middle, and the fall is low enough to reach Scale 2. As for the two falling tones, the revised T-scales via Fon and Chiang's version support Yip (2002) claim that "in many Asian languages the tonal range can be divided into two pitch registers, and contour (tone) typically belongs to one register or the other, with 3, the mid pitch, falling on the boundary between the two" (p. 22). Thus, the revised T-scales of the high falling tone and the low falling tone, [53] and [31], via Fon and Chiang's version has the Scale 3 in the middle. Tone3[31] belongs to the lower register, whereas Tone4[53] belongs to the upper register.

As for the two checked tones, [3] and [4] via Fon and Chiang's version, and [43] and [54] via Shi's version indicate that the two versions are in fact very similar, only that the onset T-scales via Shi's version start with a higher scale respectively. However, those via Shi's version indicate that the two checked tones show falling contours.

As for Tone2, both versions show that it is a concave tone, [313] via Fon and Chiang's version and [312]. However, when we look into the original pitch value in Hz shown in Table 3.1, the BP of Tone2 is in fact a little higher than the EP. Via Fon and Chiang's version, both BP and EP are in Scale 3, whereas via Shi's version, EP is in Scale 2, which exhibits a lower scale than its BP. As for Tone7, only Shi's version shows a phonetic fall in the middle and the T-scale is hence [324], rather than [34]. Note that there is only one-scale difference between the EP and the BP of this rising tone, whereas for falling tones, there is a two-scale difference. Ohala (1978) argued that falling tones were different from rising tones in many ways. For example, Black and 't Hart argued that falling contours must cover a greater pitch range than a rising contour in order to be perceived with a given level of "prominence" (as cited in Ohala, 1978, p. 30). This claim was supported by the revised tonal representations in Ta-pu Hakka as well. In this language, the T-scale of the rising tone was [34] has one-scale difference, whereas the falling tones [53] and [31] have two-scale difference. Ohala (1978) further argued that "this asymmetry may be of auditory origin and speakers may modify their articulation to accommodate the listeners" (p. 30). However, the results of our study also suggest that this asymmetry is also articulatory in nature.

It seems that both versions have its advantages and disadvantages. Therefore, we are unable to decide which version actually shows a better way of denoting tones in Ta-pu Hakka. Fon and Chiang's version are based semitone, whereas Shi's function is based on Hz. In order to compare the tonal scales obtained from the two versions, we convert the pitch value in Hz obtained via Shi's function into semitone and try to find out the correlation between the two versions and the results were illustrated in Figure 3.3.

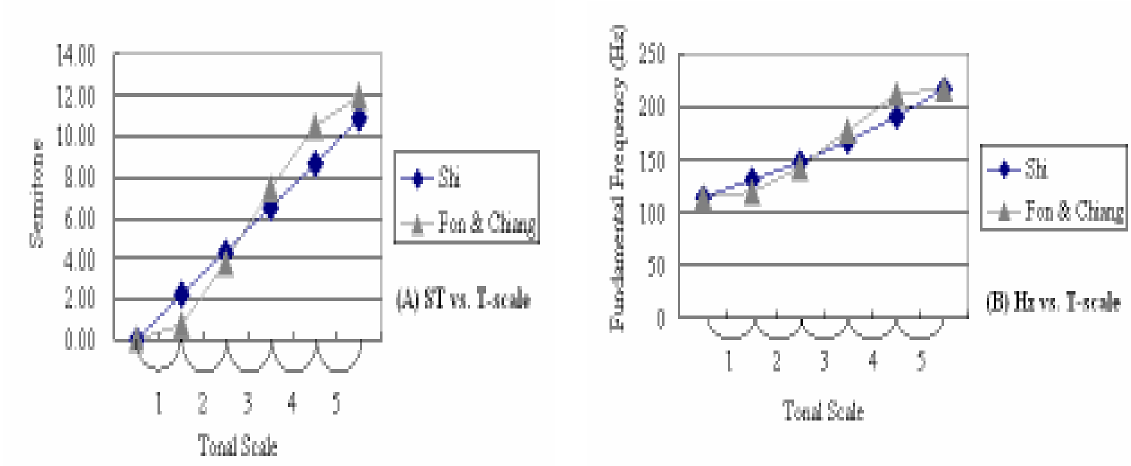


Figure 3.3: Correlation between Shi's and Fon & Chiang's Versions

Figure 3.3 (A) shows the correlation between semitone and T-scale, whereas (B) shows the correlation between Hz and T-scale. As can be seen from Figure 3.3 (A), Shi's function, when converted to semitone, in fact showed a kind of linear correlation, whereas Fon and Chiang's version still showed a non-linear correlation. If we convert Fon and Chiang's version back into Hz, the correlation between Hz and T-scale of their version still maintains a non-linear correlation as shown in Figure 3.3 (B). Shi's version, on the contrary, does not show a very clear non-linear correlation even though his function is exponential. Xu, Gandour and Francis (2006) found that the perception of tone was categorical, which suggests a non-linear correlation in tone perception as well as in tone production.

After comparing the correlation between T-scale and Hz or semitone, we assume that Fon and Chiang's version might be more suitable in verifying tonal representations in Ta-pu Hakka because the revised T-scales will show a very obvious non-linear correlation.

Fon and Chiang's (1999) formulae sheds a light on verifying tonal representations. However, we found that their original formulae needed to be adjusted and modified according to different pitch ranges among different groups of speakers. As a consequence, their formulae seem to be more complicated because two steps of calculation would be needed: (1) converting Hz to semitone; (2) converting N (semitone) into T-scale. Nevertheless, since their formulae are able to show a non-linear correlation of the T-scales, we still believe that the formulae postulated and constructed by Fon and Chiang (1999), which originated from Chao's (1968) second version, are more suitable for verifying tonal representations, at least in Ta-pu Hakka.

To sum up, the RTRs via our reconstructed formulae based on Fon and Chiang's (1990) formulae and via Shi's (1990) logarithmic function answer the first research question in the present study. The results showed that there is some incongruence between phonological representations and their phonetic realizations, but the contrast between pair-off tones can still be seen. The differences between phonological representations and phonetic realizations lead us to the following assumptions:

(1) Tonal representations of the citation tones in Ta-pu Hakka are suggested as follows: Tone1 as [33], Tone2 as [313], Tone3 as [31], Tone4 as [53], Tone 5 as [3̲], Tone6 as [4̲], and Tone7 as [34].

(2) We assume that all the level and rising tones would show phonetic characteristic like concave tones do. The valley in a level tone, however, may not reach a lower scale, so the phonetic fall in the middle of the syllable is not obvious in a level tone.

(3) A rising tone, which used to be thought of having a rising contour only, in fact shows a dipping characteristic. If the dipping is low enough, the rising tone will turn a concave tone according to its phonetic realization.

(4) If there are two falling tones in a tone language, [53] and [31] would be better representations because they can be paired off—one belongs to the upper register and the other belongs to the lower register.

(5) When there are more tones in a tone language, such as seven in Ta-pu Hakka, these tones are more equally distributed along the 5-scaled system and the average pitch range of these tones is larger than a tone language with less tones.

(6) The revised tonal representations of Ta-pu Hakka not only show the phonetic realizations of Hakka tones, but also indicate that these tones in this language can be paired off, showing contrast and comparison correlation.

After verifying the tonal representations of the citation tones, that is, tones in isolated syllable, we will further explore the tonal representations in disyllabic words.

Via disyllabic words, we can verify the tonal representations of sandhi tones along with those in WI and WF positions.

3.2 Tonal Representations Revised via Disyllabic Words

Although we assume that Fon and Chiang's (1999) version of verifying tonal representations in Ta-pu Hakka is more suitable because it can show a non-linear correlation between pitch values and tonal scales, Shi's (1990) logarithmic function will still be used to verify the tonal representations in disyllabic words besides Fon and Chiang's version. In in Section 3.2.1, we will explore and verify the tonal representations of sandhi tones in word-initial (WI) positions. In Section 3.2.2, we will verify the tonal representations of tones which do not undergo tone sandhi rules in WI and WF (word-final) positions.

3.2.1 Tonal Representations of Disyllabic Words

In this section, the tones that did not undergo tone sandhi rules were denoted as their revised tonal representations (RTR) via Fon and Chiang's (1999) version. As for the sandhi tones, the tonal representations adopted were their original ones based on ***Ta-pu Hakka Dictionary*** (Shü et al., 2005). Table 3.7 showed the mean pitch values of BP, EP, Peak and Valley in WI syllables and Table 3.8 showed those in WF syllables.

Table 3.7: Mean pitch value of BP, EP, Peak and Valley of WI syllables (SD=Std. deviation. RTR=revised tonal representations. OTR=original tonal representations.)

TONE (Case No.)	WI	BP (Hz)	EP (Hz)	Peak (Hz)	Valley (Hz)
T[3]-RTR	Mean	179.77	163.56	179.96	160.78
(165)	SD	54.92	49.51	54.86	47.88
T[31]-RTR	Mean	187.81	148.83	188.24	147.24
(168)	SD	54.31	47.84	54.24	46.38
T[323]-RTR	Mean	147.54	130.18	148.43	125.01
(144)	SD	47.64	39.15	47.29	37.83
T[33]-RTR	Mean	168.06	157.70	169.24	155.19
(96)	SD	52.99	49.67	51.94	48.77
T[4]-RTR	Mean	210.83	204.23	211.81	201.66
(168)	SD	65.13	62.60	64.99	61.31
T[53]-RTR	Mean	221.44	164.52	225.05	162.25
(72)	SD	69.01	51.78	67.88	50.17
ST-[55]-OTR	Mean	197.83	182.40	199.23	180.54
(96)	SD	61.43	59.45	60.69	58.30
ST-[35]-OTR	Mean	160.27	190.79	197.71	153.91
(72)	SD	49.67	54.85	57.14	46.78
ST-[33]-OTR	Mean	168.43	159.41	168.51	157.11
24	SD	53.94	51.63	53.94	51.21

Table 3.8: Mean pitch value of BP, EP, Peak and Valley of WF syllables (SD=Std. deviation. RTR=revised tonal representations.)

TONE (Case No.)	WI	BP (Hz)	EP (Hz)	Peak (Hz)	Valley (Hz)
T[3]-RTR	Mean	183.54	168.92	186.88	163.57
(143)	SD	54.92	57.12	58.19	52.18
T[31]-RTR	Mean	175.63	127.07	175.83	125.51
(144)	SD	48.89	37.10	48.92	35.82
T[323]-RTR	Mean	138.74	137.24	148.66	115.05
(143)	SD	52.34	55.23	57.18	39.55
T[33]-RTR	Mean	161.81	149.51	163.02	145.03
(144)	SD	51.02	50.43	51.73	47.71
T[34]-RTR	Mean	157.01	183.53	190.76	149.75
(144)	SD	45.93	59.90	61.92	42.90
T[4]-RTR	Mean	194.76	190.38	204.04	182.60
(144)	SD	62.07	54.93	61.01	54.63
T[53]-RTR	Mean	205.20	154.16	208.94	150.25
(144)	SD	60.34	47.40	61.11	43.60

By using the obtained average pitch value of the four measured points, we then converted those pitch values in Hz into T-scales via reconstructed formulae based on Fon and Chiang's (1999) version and via Shi's logarithmic function. The obtained N values and their corresponding T-scales in WI and WF positions were shown in Table 3.9. As can be seen from this table, the pitch range (pitch space) in WI and WF were 10.18 and 10.33 semitones respectively, which were close to 11 semitones. Thus, we further modified the formulae based on the 11-semitone pitch range. The revised formulae were shown as follows.

(24) *Tone#* = N/**2.75**+1 (if N≧**4.125**)
(25) *Tone#* = Tone3 (if **3.4375**≦N<**4.125**)
(26) *Tone#* = Tone2 (if **0.6875**≦N<**3.4375**)
(27) *Tone#* = Tone1 (if 0≦N<**0.6875**)

The results of converting Hz to semitones in both positions were also shown in Table 3.9 along with the revised T-scales.

Table 3.9: T-scale revised via Fon and Chiang's (1999) version in word-initial (WI) and word-final (WF) positions. (ST=sandhi tones; surface tones: tones that do not undergo sandhi rules; CT= citation tones; OTR: original tonal representations in *Ta-pu Hakka Dictionary*; RTR= revised tonal representations)

Position	OTR	RTR (CT)	Semitone (N)				T-scale				RTR
			BP	EP	Peak	Valley	BP	EP	Peak	Valley	
WI (surface tone)	2	3	6.29	4.65	6.31	4.36	3.29	2.69	3.29	2.58	3
	31	31	7.05	3.02	7.09	2.83	3.56	2.00	3.58	2.00	42
	113	313	2.87	0.70	2.97	0.00	2.00	2.00	2.00	1.00	212
	33	33	5.12	4.02	5.24	3.74	2.86	3.00	2.91	3.00	33
	5	4	9.05	8.50	9.13	8.28	4.29	4.09	4.32	4.01	4
	52	53	9.90	4.75	10.18	4.51	4.60	2.73	4.70	2.64	53
ST	35	34	4.30	7.32	7.94	3.60	2.56	3.66	3.89	3.00	34
	55	/	7.95	6.54	8.07	6.36	3.89	3.38	3.93	3.31	43
	33	/	5.16	4.21	5.17	3.96	2.88	2.53	2.88	2.44	33
WF (surface tone)	2		8.09	6.65	8.40	6.09	3.94	3.42	4.05	3.22	43
	31		7.32	1.72	7.34	1.51	3.66	2.00	3.67	2.00	42
	113		3.24	3.05	4.44	0.00	2.00	2.00	2.61	1.00	212
	33		5.90	4.54	6.03	4.01	3.15	2.65	3.19	3.00	33
	35		5.38	8.08	8.75	4.56	2.96	3.94	4.18	2.66	34
	5		9.11	8.72	9.92	8.00	4.31	4.17	4.61	3.91	4
	52		10.02	5.07	10.33	4.62	4.64	2.84	4.76	2.68	53

The tonal representations via the formulae modified based on Fon and Chiang's (1999) version showed that Tone5, the low-checked tone, was given different T-scales:

[3] in WI and [43] in WF. Does this result indicate that Tone5[3] has a steeper falling slope in WF than in WI position? Does a one-scale difference indicate a steeper slope than a zero-scale difference between its BP and EP? The comparison of Tone5[3] in different prosodic positions, i.e., WI and WF, will be discussed in Section 4.3.3. So far, we can only infer from the result that the T-scales of Tone5 were different in WI and WF positions.

The most interesting result was the revised T-scales of Tone2[313]. In WI and WF, it still remained as a concave tone with the T-scale [212]. However, the EP in WI almost fell to Scale 1, indicating that it was in fact more like a falling tone.

For falling tones, the T-scale was reduced to one-scale difference, [42] and [53] respectively, no matter they were in WI or WF position. The sandhi tone of Tone4[53] was [43], very similar to its original underlying tone. Does this indicate that the ***Chü*** sandhi rule is not evident in Ta-pu Hakka? When we looked back into the original data in Hz, we would find that the pitch values of the four measured point of the ST-Tone4 were in fact different from Tone4, indicating that they were still different. In order to test the hypothesis, statistical comparisons will be conducted in Section 3.2.2 in order to investigate if the ***Chü*** sandhi rule is evident.

We would further adopt Shi's logarithmic function to verify the tonal representations in disyllabic words. The results were shown in Table 3.10.

Table 3.10: T-scale revised via Shi's (1990) function in word-initial (WI) and word-final (WF) positions. (ST=sandhi tones; surface tones: tones that do not undergo sandhi rules; CT= citation tones; OTR: original tonal representations in *Ta-pu Hakka Dictionary*; RTR= revised tonal representations via Shi's function)

	OTR	RTR (CT)	WI				RTR	WF				RTR
			BP	EP	Peak	Valley		BP	EP	Peak	Valley	
surface tone	2	43	3.09	2.29	3.10	2.14	43	3.91	3.22	4.06	2.95	4
	31	41	3.46	1.48	3.48	1.39	42	3.54	0.83	3.55	0.73	41
	113	312	1.41	0.34	1.46	0.00	211	1.57	1.48	2.15	0.00	212
	33	33	2.52	1.98	2.58	1.84	32	2.86	2.20	2.92	1.94	323
	5	54	4.44	4.17	4.48	4.07	5	4.41	4.22	4.80	3.87	5
	52	52	4.86	2.34	5.00	2.22	53	4.85	2.45	5.00	2.24	53
	35	34						2.61	3.91	4.24	2.21	34
ST	35	/	2.11	3.60	3.90	1.77	324					
	55	/	3.90	3.21	3.96	3.13	44					
	33	/	2.54	2.07	2.54	1.94	323					

Note that in Table 3.10, the RTRs of citation tones represented the T-scales revised via Shi's function, not via Fon and Chiang's formulae. We can see from this table that the T-scales of Tone5, the low checked tone, were also different in WI and WF positions, but the revised T-scales were just contrary to those via Fon and Chiang's (1999) version. Via Shi's function, it was [43] in WI and [4] in WF, whereas it was [3] in WI and [43] in WF via Fon and Chiang's version. In Section 4.2, statistical comparison will be conducted to explain how checked tones are different from each other when in WI and WF positions.

As for the concave tone Tone2, its T-scales in WI position was different from that via Fon and Chiang's version. It became a falling tone [211] in WI, and maintained a concave tone [212] in WF. The dipping characteristic also existed in Tone1[33] in WF, which became [323], and in Tone7[324], which remained [324] as its citation form via Shi's function.

What was different from Fon and Chiang's results was that ST of Tone4[52] was [44], which was different from the non-sandhi tone [53] in both positions. This result might imply that the ***Chü*** sandhi rule might still be evident if we adopt the revised version via Shi's function. Still, statistical comparison is needed in order to prove if this sandhi rule is evident, which will be discussed in the next section.

3.2.2 Sandhi Tones in Word-Initial Position

Starting from this section, all the tonal representations would be tentatively presented by adopting the RTRs based on Fon and Chiang's version. However, when referring to the tone sandhi rules, we still used the tone numbers assigned in this paper as have been introduced in Table 1.2.[21] In this section, Section 3.2.2.1 presented the comparison of Tone7 as a sandhi tone and as a citation tone. In Section 3.2.2.2, the comparison between Tone1 and ST-Tone1 would be discussed. As for the comparison between Tone4 and ST-Tone4, it would be presented in Section 3.2.2.3.

3.2.2.1 Tone1[33] Sandhi Rule

As we have mentioned in Chapter Two that Tone7[34] in the word-initial position of a disyllabic words were all sandhi tones of Tone1[33]. Thus, the revised T-scale of Tone7[34] in WI position would be referred to as sandhi tone (ST). The Tone1[33] sandhi rule was presented again in (28).[22]

(28) Tone1→ Tone7／____{Tone1, Tone3, Tone5}

In order to test if Tone7 in WI position (ST-Tone1) was different from its underlying tone Tone1, an independent *t*-test was conducted. The results were shown in Table 3.11.

Table 3.11: Comparing means of Tone1 and ST-Tone1 in WI (ST: sandhi tone; SD=Std. deviation)

Parameters	Tone Type	N	Mean	SD	One-sample Independent *t*-test
BP (Hz)	Tone1	120	168.13	52.95	$t(190)=1.0195, p=0.309$
	ST-Tone1	72	160.27	49.67	
EP (Hz)	Tone1	120	158.04	49.85	$t(190)=-4.2420, p<.05$
	ST-Tone1	72	190.79	54.85	
Peak (Hz)	Tone1	120	169.09	52.12	$t(190)= -3.5512, p<.05$
	ST-Tone1	72	197.71	57.14	
Valley (Hz)	Tone1	120	155.57	49.06	$t(190)= 0.2314, p=0.817$
	ST-Tone1	72	153.91	46.78	
Mean (Hz)	Tone1	120	161.38	49.17	$t(190)=-1.7355, p=0.084$
	ST-Tone1	72	174.11	49.22	
DURATION (ms)	Tone1	120	237.04	76.69	$t(190)= 0.0088, p=0.993$
	ST-Tone1	72	236.94	69.24	
SLOPE (Hz/ms)	Tone1	120	-0.0443	0.0458	$t(190)= 22.5958, p<.05$
	ST-Tone1	72	0.1365	0.0649	

The statistical results in Table 3.11 showed that the differences between all the measured parameters of ST-Tone1 and Tone1 were significantly different in EP, Peak pitch value, and the slope. For the pitch value of EP, ST-Tone1 was higher than its underlying Tone1 in WI, $t(190) = -4.2420$, $p<.05$. The pitch value of the Peak of ST-Tone1 was also higher than Tone1, $t(190) = -3.5512$, $p<.05$. The slope of ST-Tone1 was much steeper than Tone1, $t(190) = 22.5958$, $p<.05$. On the other hand, the pitch values of BP and Valley of Tone1 does not show significant difference from its sandhi tone. However, when we looked into the revised T-scales of Tone1 and its sandhi tone, the T-scales were both given [323] via Fon and Chiang's (1999) formulae. Thus, the result suggests that T-scales of the sandhi tones might not be proper indicators of determining whether a sandhi rule is evident or not. However, if we look into the revised T-scales via Shi's (1990) function, we found that Tone1 was given [32] and ST-Tone1 was given [324], which indicated that the slope of the latter was positive whereas it was negative for the former. Thus, T-scales of disyllabic words via Shi's function seemed to be able to show the phonetic and statistical realizations of sandhi tones. So far, it seemed that Shi's logarithmic function was better in verifying the T-scales of disyllabic words.

3.2.2.2 Tone2[313] Sandhi Rule

Another sandhi tone Tone33, which is the sandhi tone of Tone2, shared the same T-scale with Tone1. The tone sandhi rule was presented in (29).

(29) Tone2→ Tone[33]-OTR／____{Tone2}

A one-sample independent *t*-test was conducted to compare the means between ST-Tone2 and the non-sandhi Tone1 in WI position. Table 3.12 showed the statistical results of the average pitch value of each measured point and the average pitch, duration, and slope of the whole syllable.

Table 3.12: Comparing means of Tone1 and ST-Tone2 in WI (ST: sandhi tone; SD=Std. deviation; ST-Tone2: the sanhi tone of Tone2)

Parameters	Tone Type	N	Mean	SD	One-sample Independent *t*-test
BP (Hz)	ST-Tone2	24.00	168.43	53.94	*t*(118)=0.0307, *p*=0.976
	Tone1	96.00	168.06	52.99	
EP (Hz)	ST-Tone2	24.00	159.41	51.63	*t*(118)=0.1490, *p*=0.882
	Tone1	96.00	157.70	49.67	
Peak (Hz)	ST-Tone2	24.00	168.51	53.94	*t*(118)= -0.0613, *p*=0.951
	Tone1	96.00	169.24	51.94	
Valley (Hz)	ST-Tone2	24.00	157.11	51.21	*t*(118)= 0.1713, *p*=0.864
	Tone1	96.00	155.19	48.77	
Mean (Hz)	ST-Tone2	24.00	162.36	51.94	*t*(118)=0.1087, *p*=0.914
	Tone1	96.00	161.14	48.73	
DURATION (ms)	ST-Tone2	24.00	216.75	69.76	*t*(118)= -1.4561, *p*=0.148
	Tone1	96.00	242.11	77.83	
SLOPE (Hz/ms)	ST-Tone2	24.00	-0.047	0.03	*t*(118)= -0.2916, *p*=0.771
	Tone1	96.00	-0.044	0.05	

As can be seen from this table, no significant differences between the two kinds of tones were found. The result implied that the phonetic realizations of ST-Tone2 were almost the same as Tone1, which indicated that this sandhi rule was evident because ST-Tone2 completely turned another tone, and it was given the same T-scale as Tone1 in previous literature.

3.2.2.3 Tone4[53] Sandhi Rule

Tone4 was another tone that would undergo tone sandhi rule, turning Tone[55]-OTR when it was followed by Tone3, Tone4, Tone5, or Tone6. The rule was again presented in (30).

(30) Tone4→Tone[55]-OTR／____{Tone3, Tone4, Tone5, Tone6}

To compare the means of all the parameters measured between Tone4 and its sandhi tone, an independent *t*-test was carried out to test if the ST-Tone4 was significantly different from the non-sandhi Tone4 when they were both in WI. The means of the measured parameters and the result of *t*-test were shown in Table 3.13.

Table 3.13: Comparing means of all the measured parameters of Tone4 and ST-Tone4 and the result of *t*-test (ST: sandhi tone; SD=Std. deviation)

	TONE	N	Mean	SD	One-sample Independent *t*-test
BP (Hz)	Tone4	72	221.44	69.01	t (166)=2.3378, p<.05
	ST-Tone4	96	197.83	61.43	
EP (Hz)	Tone4	72	164.52	51.78	t (166)= -2.0364, p<.05
	ST-Tone4	96	182.40	59.45	
Peak (Hz)	Tone4	72	225.05	67.88	t (166)=2.5939, p<.05
	ST-Tone4	96	199.23	60.69	
Valley (Hz)	Tone4	72	162.25	50.17	t (166)=-2.1333, p<.05
	ST-Tone4	96	180.54	58.30	
Mean (Hz)	Tone4	72	195.35	56.29	t (166)=0.5326, p=0.595
	ST-Tone4	96	190.61	57.70	
DURATION (ms)	Tone4	72	218.63	78.77	t (166)=-1.2429, p=0.216
	ST-Tone4	96	232.69	67.51	
SLOPE (Hz/ms)	Tone4	72	-0.27	0.18	t (166)=-9.2412, p<.05
	ST-Tone4	96	-0.08	0.08	

As can be seen from this table, Tone4 and ST-Tone4 showed significant differences in the following measured points: the average pitch value in Hz of the beginning point, the ending point, the peak, and the valley. Only the mean F0 and the duration of the whole syllable were not significantly different. Obviously, the average pitch values of these measured points in Tone4 as a non-sandhi tone were higher than those of its sandhi tone. When comparing the slope, we found that the slope of Tone4 was much steeper than that of the ST-Tone4, t (166)=-9.2412, p<.05. Therefore, we could also prove that the tone sandhi rule (30) in Ta-pu Hakka was also evident.

When we referred to the tonal representations revised via Fon and Chiang's version, we found that the two types of tones were both given [43], but their statistical facts were in fact different. On the other hand, when we looked into the revised T-scales via Shi's function, Tone4 as a non-sandhi tone was given [53], and ST-Tone4 was given [44]. Thus, the revised T-scales via Shi's function complied with the statistical facts that the slope of Tone4 was steeper than the ST-Tone4. Again, T-scales revised via Shi's function were closer to the statistical results.

3.2.3 Discussion of the Two Revised T-scales

Table 3.14 shows the RTRs via Fon and Chiang's (1999) version and via Shi's (1990) function. Shi's logarithmic function, thought exponential, in fact shows a more linear correlation, while Fon and Chiang's (1999) version shows a non-linear correlation as have been discussed in Section 3.1.3. Via Fon and Chiang's formulae, Scale 3 occupies the largest governing pitch span than other four scales, which may be the reason why the T-scales via Fon and Chiang's formulae cannot be treated as indicators of the slope.

Table 3.14: Revised tonal representations of the two versions (CT=citation tone; ST=sandhi tone)[23]

Tone No.	OTR in ***Ta-pu Hakka Dictionary***	Fon and Chiang's Version			Shi's Version		
		Mono-syllabic Words	Disyllabic Words (WI)	Disyllabic Words (WF)	Mono-syllabic Words	Disyllabic Words (WI)	Disyllabic Words (WF)
T1	33	33	33	33	33	32	323
T2	113	313	212	212	312	211	212
T3	31	31	42	42	41	42	41
T4	52	53	53	53	52	53	53
T5	2	3	3	43	43	43	4
T6	5	4	4	4	54	5	5
T7 (ST)	35	34 (CT)	34 (ST)	34	34 (CT)	324 (ST)	34
ST	55		43			44	
ST	33		33			323	

As can be seen from this table, the RTR in disyllabic words via Fon and Chiang's version were very similar to their citation tones. For Tone2, the BP and EP seemed to be lowered, and for Tone3, the two points seemed to be raised. The results of comparing sandhi tones and the tones with similar tonal scales in Section 3.2.2 suggest that the revised T-scales via Shi's (1999) logarithmic function are better in showing the phonetic realizations of tones in disyllabic words. The statistical results also indicate that the three sandhi rules in disyllabic words in Ta-pu Hakka are evident.

However, we find it rather uneasy to use the revised tonal representations to describe the tonal variations and the sandhi tones in disyllabic words. Therefore, we postulate that the revised tonal representations in disyllabic words are not proper for describing tones. Furthermore, they cannot be used as the norm of representing tones like Shen & Lin (1991) claimed. They asserted that "the acoustic properties of tones in isolated citation form are not appropriate for use as norms in investigating tones in connected speech" (Shen & Lin, p. 431). On the contrary, we believe that if we want to set up the citation tones in a tone language, tonal representations via isolated syllables should be regarded as the norm.

The similar assertion like Shen and Lin's were made by Chang (1995) and Huang (2003). They both considered that the tonal representations in WF positions are the same as the citation tones in isolated syllables and those tonal representations in WF position can be considered as citation tones. However, the revised tonal representations in WF in the present study suggest that tones in disyllabic words are not given exactly the same T-scales as in isolated syllables. We assume that the tones in disyllabic words, whether in WI or WF, do not show the same properties and characteristics of their corresponding tones in isolated syllables because they are influenced by their neighboring tones to some extent. Thus, the tonal representations in disyllabic or multi-syllabic words would be more appropriate for exploring and verifying the phonetic realizations of sandhi tones, not for verifying the citation tones in a tone language.

However, counterevidence shows that even the revised tonal representations of the sandhi tones are not appropriate for proving the existence of tone sandhi rules in Ta-pu Hakka. For example, via Fon and Chiang's version, the non-sandhi tone of Tone4 and ST-Tone4 are both assigned with the T-scale [43], which indicates that ST-Tone4 is exactly the same as its underlying tone [43]. As a result, the revised tonal representations of ST-Tone4 seems to imply that this sandhi rule is not evident, which is just opposite to the statistical results shown in Section 3.2.2.3. This counterevidence shows that even the tonal representations of sandhi tones are not appropriate for investigating whether sandhi rules are evident or not, at least in Ta-pu Hakka. In order to explore the existence of sandhi rules, statistical comparison is required.

3.2.4 Interim Summary

By using disyllabic words, we hope to explore the phonetic realizations of the sandhi tones of Tone1, Tone2, and Tone4 in Ta-pu Hakka. However, the results indicate that Shi's (1990) logarithmic function is better in representing sandhi tones, even though it shows a nearly linear correlation between fundamental frequency and its corresponding T-scale. The formulae reconstructed based on Fon and Chiang's (1999) version are more appropriate for verifying the citation tones. Through the discussion of the revised tonal representations of sandhi tones in Section 3.2.3, we suggest that tonal representations of Ta-pu Hakka via disyllabic words alone can not be used to decide whether the sandhi rules are evident or not. Statistical results should be taken into consideration, and they are in fact the most important criteria of deciding whether the sandhi tones are different from their underlying tone.

3.3 Checked Tones Comparison

The T-scales of the two checked tones in three positions—in isolated syllable, in WI and WF of disyllabic words—were almost the same. The results were shown in Table 3.15 for easy reference. The T-scale of the low-checked tone in WF position of disyllabic words was changed into 43 via Fon and Chiang's version, while it became 43 in WI position via Shi's function. The revised T-scales in fact were not consistent and confusing. Does the low checked tone have a steeper falling slope in WI or WF position? The statistical results of the low checked tone in three positions were shown in Table 3.16, and those of the high checked tone were shown in Table 3.17.

Table 3.15: Revised checked tones in different contexts via the two versions

Fon and Chiang's Version			Shi's Version		
Mono-syllabic Words	Disyllabic Words (WI)	Disyllabic Words (WF)	Mono-syllabic Words	Disyllabic Words (WI)	Disyllabic Words (WF)
3	3	43	43	43	4
4	4	4	54	5	5

Table 3.16: CT-Tone5[3]: Mean and standard deviation of all measured parameters in citation form and in WI and WF positions

Position (No.)	BP (Hz)	EP (Hz)	PEAK (Hz)	VALLEY (Hz)	MEAN (Hz)	DU (sec.)	SLOPE
CT (12)	166.64	148.14	166.75	147.88	157.72	0.11	-172.49
	(53.59)	(43.85)	(53.67)	(43.97)	(49.84)	(0.04)	(143.99)
SI (165)	179.72	163.56	179.91	160.78	169.19	0.11	-161.35
	(54.89)	(49.51)	(54.83)	(47.88)	(49.82)	(0.05)	(113.96)
WF (143)	183.54	168.92	186.88	163.57	175.47	0.09	-207.44
	(54.92)	(57.12)	(58.19)	(52.18)	(54.19)	(0.05)	(216.73)

Table 3.17: CT-Tone6[4]: Mean and standard deviation of all measured parameters in citation form and in WI and WF positions

Position (No.)	BP (Hz)	EP (Hz)	PEAK (Hz)	VALLEY (Hz)	MEAN (Hz)	DU (sec.)	SLOPE
CT	196.44	185.52	196.86	183.35	190.62	0.15	-74.43
(12)	(51.98)	(48.60)	(51.80)	(47.27)	(50.76)	(0.07)	(138.94)
SI	211.06	204.25	211.88	201.68	206.85	0.12	-61.35
(168)	(64.98)	(62.59)	(64.81)	(61.29)	(62.59)	(0.06)	(80.38)
WF	198.25	190.36	203.83	185.11	194.90	0.14	-77.93
(144)	(61.66)	(54.94)	(60.90)	(54.52)	(57.26)	(0.07)	(169.73)

For the low checked tone, we found that the hierarchy of slope in the three positions was as follows: WF>CT>WI. The hierarchy of slope of the high checked tone was the same. So far, the similar revised T-scales of the two checked tones also raised the question as to what the criteria of distinguishing the two checked tones in Ta-pu Hakka are. Would the slope of the low checked tone be steeper than that of the high checked tone?

In order to explore the criteria of distinguishing the two checked tones in different positions, an independent *t*-test was conducted. We compared the means of all the measured parameters of the low checked tone and the high checked tone in WI position, and the results were shown in Table 3.18, and the results of the two checked tones in WF position were shown in Table 3.19.

Table 3.18: Results of t-test comparing means between Tone5[3] and Tone6[4] in WI position

Position (No.)	BP (Hz)	EP (Hz)	PEAK (Hz)	VALLEY (Hz)	MEAN (Hz)	DU (sec.)	SLOPE
Tone3	179.72	163.56	179.91	160.78	169.19	0.11	-161.35
(165)	(54.89)	(49.51)	(54.83)	(47.88)	(49.82)	(0.05)	(113.96)
T4	211.06	204.25	211.88	201.68	206.85	0.12	-61.35
(168)	(64.98)	(62.59)	(64.81)	(61.29)	(62.59)	(0.06)	(80.38)
t(331)	-4.75	-6.57	-4.86	-6.78	-6.07	-1.67	-9.27
				$p<.05$			

Table 3.19: Results of t-test comparing means between Tone5[43] and Tone6[4] in WF position

Position (No.)	BP (Hz)	EP (Hz)	PEAK (Hz)	VALLEY (Hz)	MEAN (Hz)	DU (sec.)	SLOPE
Tone43	183.54	168.92	186.88	163.57	175.47	0.09	-207.44
(143)	(54.92)	(57.12)	(58.19)	(52.18)	(54.19)	(0.05)	(216.73)
Tone4	198.25	190.36	203.83	185.11	194.90	0.14	-77.93
(144)	(61.66)	(54.94)	(60.90)	(54.52)	(57.26)	(0.07)	(169.73)
t(285)	-2.13	-3.24	-2.41	-3.42	-2.95	-7.20	-5.64
				$p<.05$			

We found that even the T-scales of the two checked tones were very close to each other, the statistical results indicated that all the parameters measured in this study were significantly different between the two checked tones, no matter in WI or WF position. As can be seen from the T-scales 4 and 3, we could conclude that the average pitch height of Tone4 was higher than that of Tone3, which could also be seen from the statistical results in Table 3.18 and 3.19.

What was worth noticing was that the slope of the low checked tone was much steeper than that of the high checked tone both in WI position, $t(331)=-9.27$, $p<.05$, and in WF position, $t(285)= -5.64$, $p<.05$. The result was the same as Chang's (1995) claim that the slope of the low check tone in Ssu-hsien Hakka was steeper than that of the high checked tone. The results in our study of Ta-pu Hakka also proved that the slope of the low checked tone was steeper than the high checked tone, which was not easy to tell merely from the revised T-scales.

To sum up, phonologically, the original T-scales of the two checked tones, [5] and [2] in ***Ta-pu Hakka Dictionary*** (Shü et al., 2005), were denoted with widely separated T-scales, so they would be easier for Hakka speakers or learners to distinguish one from the other. Since the two checked tones both showed downward tendency, which resulted in the negative value of their slope, it was quite impossible to denote the T-scale of the low checked tone as "1". Because "1" was in the bottom of the five-scaled system, a T-scale of "1" was not likely to fall to anywhere. Thus, the low check tone was denoted by Hakka phonologists as Tone2 with room to form a falling contour. As a result, when seeing the T-scale of 2, a speaker will try to pronounce it by lowering their pitch, and vice versa. However, the acoustic evidence showed that phonetically the pitch span between the two checked tones was not as far as it was thought to be, only one-scale difference (4-3=1). The CT-RTR of the low checked tone was actually very close to Tung's (1995) and Chiang's (1998 a&b) tonal representations, [32] and [31] respectively. The phonological representations of the low checked tone by the two scholars in fact showed the fact that the low checked tone seemed to have a steeper slope because there was at least one-scale difference.

3.4 Intensity Comparison Among Monosyllabic Words

As we have mentioned in Chapter One, Huang (2003) found that intensity served as an assistant of duration to help distinguish checked tones from unchecked tones. In order to investigate whether checked tones in Ta-pu Hakka exhibit the same characteristics, intensity would be measured at the four points, BP, EP, the peak, and the valley, of the monosyllabic words. Average intensity of the whole syllable will be calculated too. Table 3.20 showed the average intensity of the four measured points along with the average intensity in dB. One-way ANOVA was conducted to investigate the interaction of average intensity among different tones. The results were shown in Table 3.21.

Table 3.20: Intensity: Descriptive statistics of the four measured points of monosyllabic words along with the mean intensity. (SD in parenthesis)

Total Case No.=12	Level & Rising Tones			Falling Tones		Checked Tones	
	Tone2	Tone1	Tone7	Tone3	Tone4	Tone5	Tone6
BP (dB)	62.42 (5.64)	64.75 (8.11)	62.51 (6.60)	64.89 (9.56)	63.15 (6.80)	65.72 (6.72)	62.45 (10.01)
EP (dB)	61.61 (8.70)	59.13 (6.38)	59.10 (10.51)	67.37 (10.58)	70.08 (11.73)	73.92 (9.39)	66.66 (11.26)
Maximum (dB)	77.89 (3.09)	81.01 (3.35)	80.46 (2.62)	81.18 (3.08)	83.81 (4.10)	81.69 (3.58)	82.56 (2.84)
Minimum (dB)	56.5 (4.97)	57.75 (5.89)	55.56 (6.34)	59.15 (8.83)	59.29 (3.34)	62.86 (6.72)	59.32 (9.12)
MEAN (dB)	71.91 (2.13)	74.21 (3.72)	73.81 (2.20)	73.83 (3.51)	75.49 (3.31)	74.60 (2.99)	74.67 (4.27)

Table 3.21: Mean intensity of the four measured points of monosyllabic words

Parameters	F(6, 77)	Sig.
BP (dB)	0.3802	0.890
EP (dB)	3.9193	<.05
Maximum (dB)	3.8125	<.05
Minimum (dB)	1.4951	0.191
Mean (dB)	1.4208	0.218

We found that only the intensity of EP and the maximum intensity had significant differences between groups. For the intensity of EP, F(6, 77)=3.9193, p<.05, and for the maximum intensity, F(6, 77)=3.8125, p<.05. The Post-hoc test (Bonferroni) indicated that the intensity of EP of the low checked tone Tone5[3] was the highest, and that the maximum intensity peak appeared in Tone6[4] and Tone4[53]. Note that the two checked tones along with the high falling tone Tone4[53] were found to have higher intensity than other tones in general. The intensity of EP of Tone3[31] was also higher than that of the level or rising tones. The mean plot of the results was shown in Figure 3.4. For the intensity of EP, we found that the two falling tones and the two checked tones had higher intensity than the rising or level tones. In other words, the maximum intensity seemed to be related to the T-scale of a tone. As can be seen from Figure 3.4(B), tones with T-scale of 3 at the onset had very close values of intensity. Tone4[53], which has the highest onset T-scale, also had the highest maximum intensity.

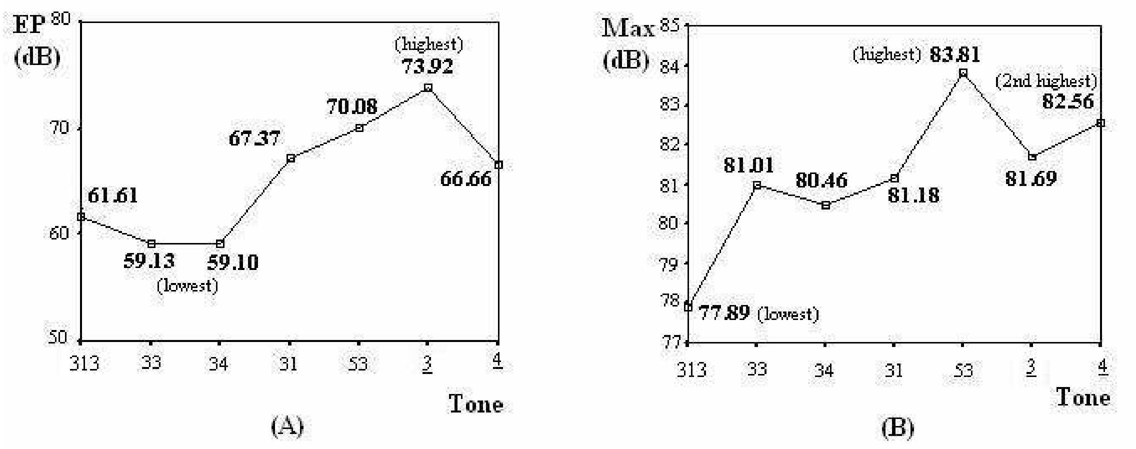


Figure 3.4: Intensity—(A): EP (dB); (B): Maximum intensity (dB)

Unlike the result found in Mei-nung Ssu-hsien Hakka by Huang (2003), intensity in general was not considered as a cue to distinguish checked tone from unchecked tones in Ta-pu Hakak. In other words, intensity did not play an important role of differentiating tones like it did in Ssu-hsien Hakka. In Ta-pu Hakka, intensity has a positive correlation with the T-scales, which is associated with pitch height (Chiang &

Chiang, 2005). As for the criterion of distinguishing checked tones from unchecked tones in Ta-pu Hakka, we found that duration was the only indicator—the duration of checked tones was shorter than unchecked tones, $t(2014)=1.992$, $p<.05$.

Other than treating intensity as a criterion of distinguishing checked tones from unchecked tones, the results shown in Table 3.20 indicated that the intensity of BP was higher than that of EP for level and rising tones. On the contrary, the intensity of EP was higher than that of BP for falling and checked tones. This results lead us to categorize level and rising tones into the same group, whereas falling and checked tones into another. Similar tendency that level or rising tones and falling or checked tones belong to two groups could also be found from the result of tonal coarticulation in Chapter Four.

3.5 Discussion and Summary of Tonal Representations

After carrying out the acoustic experiment on monosyllabic and disyllabic words in Ta-pu Hakka and verifying tonal representations via acoustic data, incongruence between phonological representations and phonetic realizations is found. The revised tonal representations of citation tones in this language should be verified based on data from isolated syllables. In the present study, the results indicate that Fon and Chiang's (1999) formulae, which shows a non-linear correlation, is more suitable for revising

T-scales, at least for tones in Ta-pu Hakka. The revised tonal representations in Ta-pu Hakka are suggested as follows: Tone1 as [33], Tone2 as [313], Tone3 as [31], Tone4 as [53], Tone5 as [3], Tone6 as [4], and Tone7 as [34].

As for the T-scales of the three sandhi tones—ST-Tone1, ST-Tone2, and ST-Tone4, the revised T-scales via Shi's (1990) logarithmic function are found to be more appropriate for showing the phonetic and statistical realizations of sandhi tones. Thus, the T-scales of three sandhi tones are suggested as follows: ST-Tone1 as [324], ST-Tone2 as [323], ST-Tone4 as [44]. Even though the revised T-scales of sandhi tones via Shi's logarithmic function are suggested, the original tonal representations of these sandhi tones would be used in investigating tonal coarticulation in Chapter Four. The three tone sandhi rules, ***Yin-Ping*** tone sandhi, ***Yang-Ping*** tone sandhi, and ***Chü*** tone sandhi, are all evident in Ta-pu Hakka. On the other hand, the revised tonal representations of tones in disyllabic words—no matter in WI or WF—should be used as reference only when investigating sandhi tones. Furthermore, they certainly cannot be regarded as the norms of citation tones—at least not for the case in Ta-pu Hakka. The citation tones in isolated syllable should be regarded as the norms of tonal representations in this language.

As for the incongruence between phonological representations and phonetic realizations in Ta-pu Hakka tones, the results in the present study show that a low level tone Tone2[11]-OTR (Chiang, 1998b) or a low-rising tone Tone2[113] or [112] (Chiang, 1998a; Lo, 1990; Shü et al., 2005; Tung, 1995) is in fact a concave tone, which has a phonetic fall (a dipping characteristic) in the middle. This kind of dipping characteristic is also found in the rising tone Tone7[34], especially when it is the sandhi tone in WI position revised via Shi's function.

For falling tones, the revised tonal representations [53] and [31] suggest that if there are two falling tones in a tone language, one will belong to the upper register, and the other will belong to the lower register (Yip, 2002). As a matter of fact, the original phonological tonal representations (Chiang, 1998 a & b; Lo, 1990; Tung, 1995) and the revised versions via Fon and Chiang's (1999) version both agree to Yip's assumption. To sum up, both auditive perception and articulatory production will try to distinguish two tones with similar acoustic realizations by separating them into two categories.

The same mechanism is also found in the two checked tones. Tone5[3] belongs to a lower register than its counterpart Tone6[4]. Though the two checked tones are revised to have very approximate T-scales, they are distinguished by their slope, and the low checked tone is found to have a steeper falling slope than the high checked tone. The difference is not statistically significant in monosyllabic words, $t(22)=-1.336$, $p=0.1952$, but it is significantly difference either in WI or WF position of disyllabic words, as was discussed in Section 3.3. Therefore, the original phonological tonal representations of the low checked tone were given [31], [32] or [21] (Lo, 1990; Tung, 1995, Chiang, 1998 a & b) to show its steeper slope. The revised T-scale of the low checked tone via Fon and Chiang's (1999) formulae is [3] may not show a steeper slope until we take the governing pitch span into consideration. That is, via Fon and Chiang's formulae, Scale 3 occupies the largest governing pitch span—3.75 out of 12 semitones—among the five scales. As a result, the T-scale [3] might be auditively perceived as [31] or [32].

In this study, the revised tonal scales are equally distributed along the five-scale system either via Fon and Chiang's (1999) formulae or via Shi's (1990) logarithmic function. Another interesting finding is that the scale 4 never appeared in the original tonal representations, whereas it replaces 5 in the high register in the cases of Tone7[34] and Tone6[4]. Only the onset F0 of the high falling tone actually reaches the top of the five-scaled system.

Furthermore, as far as the intensity is concerned, intensity may not be able to be considered as a cue to distinguish checked tones from unchecked tones. More data in monosyllabic words may be needed to prove this argument.

Verifying the tonal representations in Ta-pu Hakka is the corner-stone of our study of tonal coarticulation. We have to set up the tonal representations of Ta-pu Hakka first so that we are able to classify the combinations of the disyllabic words into a compatible or a conflicting context which will be discussed in Chapter Four.

Notes:

[20] There were originally two monosyllabic words, *[kʰjɛn]* and *[ma]* in each tone, which makes the total number of each tone 12. However, *[ma]31* was pronounced as a check tone by all the subjects because *[ma]31* usually preceded the word *[kaɪ]31*. And the combination *[ma]31_[kaɪ]31* 'what' made the preceding *[ma]31* palatalized so that the pitch contour and the formant of *[ma]31* was actually those of *[mak]31*. Therefore, the data of *[ma]31* as a monosyllabic word was excluded in this study, or it might extremely affect the average F0 and duration of Tone 31, especially the offset pitch value. Furthermore, since the data in monosyllabic words were reduced, the individual and gender differences would not be discussed in the present study.

[21] Tone1=[33], Tone2=[313], Tone3=[31], Tone4=[53], Tone5=[3], Tone6=[4], Tone7=[34].

[22] In the sandhi rules mentioned in this section, only the tone number will be used in order to avoid disturbance.

[23] Tones that are not undergo sandhi rules in disyllabic words are neither called ST nor CT, and they will be termed as their original tone number, such as Tone1, Tone2, and etc.

Chapter 4 Tonal Coarticulation in Disyllabic Words

In this chapter, tonal variations in disyllabic words in Ta-pu Hakka will be explored. In Section 4.1, we will introduce the stimuli used to investigate tonal coarticulation. As for the informants, the recording procedure, the parameters measured to explore the phonetic realizations of tonal coarticulation, they are the same as those in investigating and verifying the tonal representations in Chapter Three. Thus, the experimental design will be briefly introduced in Section 4.2. Starting from Section 4.3, we will explore the tonal coarticulation in different prosodic positions, namely WI and WF in the present study. In Section 4.4, tonal coarticulation in different tonal contexts will be discussed. Furthermore, in Section 4.5, tonal variations affected by the neighboring tones, termed as adjacent tonal effect in our study, will be investigate. In Section 4.6, we will explore the influence of the onset and offset pitch values on the adjacent tones. Through Section 4.4 to 4.6, we will also use the Target Approximation model to examine the phenomena of tonal variations in Ta-pu Hakka.

4.1 Material

The stimuli used to investigate tonal coarticulation was the inventory of disyllabic words, which were also used in verifying tonal representations of sandhi tones in Ta-pu Hakka, as has been discussed in Section 3.2. The possible tonal combinations were presented in Section 2.1. However, since we had already revised the tonal representations of the seven citation tones and the three sandhi tones, the T-scales of the tonal combinations in the test stimuli were modified and were shown in Table 4.1.

Table 4.1: Modified T-scales of the tonal combinations of the disyllabic words

CT	ST	No.	CT	ST	No.	CT	ST	No.
33_4	--	4	313_4	--	4	31_4	--	4
33_53	--	4	313_53	--	4	31_53	--	4
33_313	34_313	4	313_313	33_313	4	31_313	--	4
33_3	34_3	4	313_3	--	4	31_3	--	4
33_31	34_31	4	313_31	--	4	31_31	--	4
33_33	--	4	313_33	--	4	31_33	--	4
33_34	--	4	313_34	--	4	31_34	--	4
53_4	43_4	4	3_4	--	4	4_4	--	4
53_53	43_53	4	3_53	--	4	4_53	--	4
53_313	--	4	3_313	--	4	4_313	--	4
53_3	43_3	4	3_3	--	4	4_3	--	4
53_31	43_31	4	3_31	--	4	4_31	--	4
53_33	--	4	3_33	--	4	4_33	--	4
53_34	--	4	3_34	--	4	4_34	--	4
Total No. of test items=42(combinations)*4(items)=168								

In WI position, there were only six possible underlying tones because Tone34 appearing in WI of disyllabic words would always be regarded as the sandhi tone of Tone1. Table 4.2 was the summary of the case number of each tone occurring in both WI and WF position. For example, the case number of Tone1 in WI was 20. 4 out of 20 were in fact ST-Tone2. We categorized CT-Tone1 and ST-Tone2 together because all the measured parameters showed no significant differences as has been discussed in Section

3.2.2.2. Even though the case numbers in each group were unequal, the ratio would not be larger than 3 or more to 1. Thus, there would be no need to test the "homogeneity of variances" when any statistical analysis was to be conducted. If the ratio of the unequal number is larger than 3 or more to 1, then the test of "homogeneity of variances" is surely to be conducted first to ensure the validity of the statistical results.

Table 4.2: The case number of each tone in WI and WF positions by the six informants

Tone / position	T1	T2	T3	T4	T5	T6	T7	ST-T1	ST-T2	ST-T4	Total
WI	96	144	168	72	168	168	0	72	24	96	1008
WF	144	144	144	144	144	144	144	0	0	0	864

4.2 Subjects, Recording and Measurement

The informants, the recording procedure, and the measured parameter were exactly the same as what have been discussed in Section 2.4 and 2.5. However, the inventory adopted to explore tonal coarticulation was that of the disyllabic words only.

4.3 Prosodic Contextual Effect on Tonal Coarticulation

In this section, we investigated how a single tone behaves in different prosodic contexts, which refer to as word-initial (WI) position and word-final (WF) position (Peng, 1997).

4.3.1 Level, Concave, and Rising Tones: Tone1, Tone2, and Tone7

As we have discussed in Chapter Three, we found that level, concave, and rising tones were considered to have similar phonetic realizations comparing to falling tones and checked tones. Therefore, we would first discuss the statistical results in Tone1[33], Tone2[313], and Tone7[34]. The statistical comparison of all the measured parameters of Tone1 was shown in Table 4.3.

Table 4.3: Group statistics of Tone1[33] and the results of *t*-test

Parameters	Position	N	Mean	SD	*t* (262)	Sig. (2-tailed)
BP (Hz)	WI	120	168.13	52.95	0.9854	0.325
	WF	144	161.81	51.02		
EP (Hz)	WI	120	158.04	49.85	1.3756	0.170
	WF	144	149.51	50.43		
Peak (Hz)	WI	120	169.09	52.12	0.9467	0.345
	WF	144	163.02	51.73		
Valley (Hz)	WI	120	155.57	49.06	1.7652	0.079
	WF	144	145.03	47.71		
Mean_F0 (Hz)	WI	120	161.38	49.17	1.7281	0.085
	WF	144	150.99	48.21		
DU (ms)	WI	120	237.04	76.69	-9.7123	<.05
	WF	144	347.06	102.44		
Slope (Hz/ms)	WI	120	-0.04	0.05	-1.3685	0.172
	WF	144	-0.04	0.03		
Valley_ alignment (%)	WI	120	74.61	29.54	0.5619	0.575
	WF	144	72.76	24.07		

We found that among the parameters measured, only the duration of Tone1[33] was significantly different in different prosodic positions. Tone1[33] was longer when it was positioned in WF position in disyllabic words, $t(262)=-9.7123$, $p<.05$. That the duration was longer in the word-final position might be due to the final-lengthening effect, which was also found in Peng's (1997) study. In her study, the duration of Taiwanese tones tended to be longer in utterance-final position than in phrase-final position. As for the F0 of BP, EP, Peak, Valley, and the average pitch of the whole syllable were actually higher in WI than in WF, even though the differences did not reach significant level. However, the phonological effect of declination could still be found from the fact that the average pitch height of Tone1[33] was lowered toward the end of a syllable. Since there were no significant differences found in the pitch of BP and EP, this result also explained why the T-scales of Tone33 in WI and WF position remained the same. Figure 4.1 showed an example of the pitch contours of Tone1[33] in both positions.

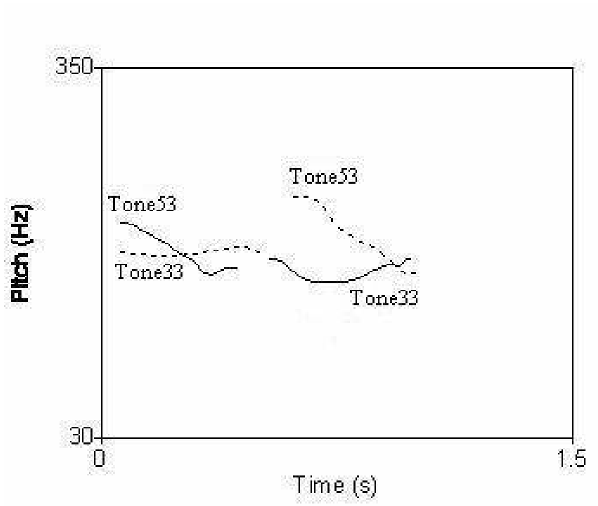


Figure 4.1: Pitch contour of Tone1[33] in WI & WF by Female_1
[pʰɔŋ]33_[pʰaɪ]53 "big and luxurious (meal)" (dotted line) vs.
[pʰaʊ]53_[tʰɔŋ]33 "take a hot-spring bath" (plain line)

The two utterances were pronounced by the same informant, Female_1, in order to eliminate idiosyncratic variations between different informants. As we can see from this figure, the pitch contour of Tone1[33] in WI and WF positions were somewhat different. The pitch contour of Tone1[33] in the word *[pʰaʊ]53_[tʰɔŋ]33* “take a hot-spring bath” showed a dipping characteristic in the middle. The revised T-scale of Tone1 in WF via Shi’s (1990) function was [323] in fact indicates the phonetic fall in the middle of the syllable.

As for Tone2[313], it was in fact a concave tone, not a low rising tone, after we verified it by using acoustic data. The results of group statistics and *t*-test were shown in Table 4.4. As can be seen this table, the pitch value of the Valley was higher in WI, $t(285)=2.1804$, $p<.05$. The duration of Tone2[313], like Tone1[33] was lengthened when it was in WI position, $t(285)=-5.0678$, $p<.05$, which also showed final-lengthening effect like Tone1. The mean slope was steeper when in WI position, $t(285)=-2.9673$, $p<.05$. Note that this tone was changed into a falling tone with the falling slope of -0.08 when it was in WI. When in WF position, its slope became much flatter, even though its value was still negative.

As for BP, EP, Peak, the average pitch values of the three measured points were not significantly different when Tone2 was in different prosodic positions. Furthermore, the average pitch values of the whole syllable in WI and WF were also very close.

Table 4.4: Group statistics of Tone2[313] and the results of *t*-test

Parameters	Position	N	Mean	SD	t(285)	Sig. (2-tailed)
BP (Hz)	WI	144	147.54	47.64	1.4894	0.137
	WF	143	138.74	52.34		
EP (Hz)	WI	144	130.18	39.15	-1.2497	0.212
	WF	143	137.24	55.23		
Peak (Hz)	WI	144	148.43	47.29	-0.0362	0.971
	WF	143	148.66	57.18		
Valley (Hz)	WI	144	125.01	37.83	2.1804	<.05
	WF	143	115.05	39.55		
Mean_F0 (Hz)	WI	144	133.60	39.25	0.8288	0.408
	WF	143	129.45	45.41		
DU (ms)	WI	144	222.05	86.49	-5.0678	<.05
	WF	144	288.54	131.55		
Slope (Hz/ms)	WI	144	-0.08	0.09	-2.9673	<.05
	WF	143	-0.02	0.23		
Valley_ alignment (%)	WI	144	73.08	28.43	8.8030	<.05
	WF	143	42.64	30.13		

What was more important was the shifting of the F0 Valley alignment. The temporal point that the Valley appeared in a syllable shifted backward when Tone2[313] was positioned in WI position in disyllabic words, $t(285)=8.8030$, $p<.05$. The F0 valley delay made this tone become more like a falling tone. We also noticed that the SD of the F0 Valley alignment in both WI and WF were very large, indicating the possibility that the F0 Valley alignment might not be influenced by their prosodic positions only, there might be some other factors that have caused this phenomenon. We postulated that it might also be influenced by their different neighboring tones.

For concave tones, we found that F0 valley alignment and slope were the factors that would determine the pitch contours. The T-scales of Tone2 in WI and WF position were [211] and [212] respectively via Shi's function (1990). The revised T-scales also implied that the pitch contour of Tone2 in WI was more like a falling tone and it was still a concave tone in WF position.

In Mandarin Chinese phonology, there was a "Half L rule" proposed by Chao (1968). Xu (2004) summarized the "Half L rule" as "The L tone, which in isolation has the purported value of 214, loses its final rise before another tone to become 21 (p. 783). This "Half L rule" was stated as in (31) (Xu, 2004, p. 783).

(31) 214→21/_T

This "Half L rule" was also true of the concave tone Tone2[313] in Ta-pu Hakka. Note that this concave tone was phonologically though of as a low tone by Chiang (1998b) and was given the T-scale [11]. As has been mentioned earlier in this section, the average slope of Tone2[313] in WI position was negative, indicating a falling pitch contour. The revised T-scale of Tone2 [211] in WI via Shi's function also showed this tendency.

An example of showing the pitch contours of Tone2 in WI and WF was given in Figure 4.2. As shown in this figure, Tone2[313] in WI did look like a falling tone, with the revised T-scale of [211], and it maintained a concave tone in WF, with the revised

T-scale of [212].

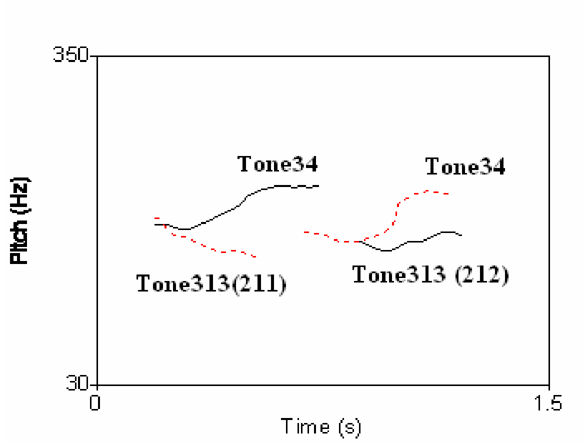


Figure 4.2: Pitch contour of Tone2[313] in WI and WF by Female_1
***[kʰi]313_[tɕʰja]34* "ride a motorcycle" vs. *[kʰɔɪ]34_[tʰɛʊ]313* "at the beginning"**

As for the high rising Tone7[34], it was in fact a sandhi tone of Tone1[33] when followed by Tone2[313], Tone3[31], and Tone5[53]. On the other hand, it was an underlying tone when in utterance final position, which was referred to as WF in the present study. The group statistics and the results of t-test were shown in Table 4.5.

The results in Table 4.5 showed that the duration was also longer in WF, $t(214)=-7.6343$, $p<.05$, which was exactly the same phenomenon as has been found in Tone1 and Tone2. So far, we could see that final lengthening existed in level, rising and concave tones in Ta-pu Hakka. However, final lengthening did not show in all the tones, as would be discussed in Section 4.3.2 and 4.3.3. Besides duration, the rising slope was larger in WI position, $t(214)=4.9177$, $p<.05$. The reason why the slope of Tone7 in WI was steeper might be owing to the tonal context effect, which would be discussed in Section 4.4.

Table 4.5: Group statistics of Tone7[34] and the results of *t*-test

Parameters	Position	N	Mean	SD	t(214)	Sig. (2-tailed)
BP (Hz)	WI	72	160.27	49.67	0.4777	0.633
	WF	144	157.01	45.93		
EP (Hz)	WI	72	190.79	54.85	0.8627	0.389
	WF	144	183.53	59.90		
Peak (Hz)	WI	72	197.71	57.14	0.7967	0.427
	WF	144	190.76	61.92		
Valley (Hz)	WI	72	153.91	46.78	0.6512	0.516
	WF	144	149.75	42.90		
Mean_F0 (Hz)	WI	72	174.11	49.22	0.5825	0.561
	WF	144	169.90	50.46		
DU (ms)	WI	72	236.94	69.24	-7.6343	<.05
	WF	144	325.00	84.71		
Slope (Hz/ms)	WI	72	0.14	0.06	4.9177	<.05
	WF	144	0.08	0.08		
Valley_ alignment (%)	WI	72	19.33	13.64	1.3798	0.169
	WF	144	16.06	17.64		

An example of the tonal contours of Tone7[34] in both WI and WF positions was given in Figure 4.3. As can be seen from this figure, the pitch contours of Tone7[34] in both positions were almost the same, which was supported by the statistical result shown in Table 4.5. Note that in this figure, Tone2[313] was revised as [211] in WI and [212] in WF position. To summarize, the longer duration of Tone7[34] in WF was owing to final lengthening effect, whereas the steeper rising slope in WI was owing to contextual tonal effect.

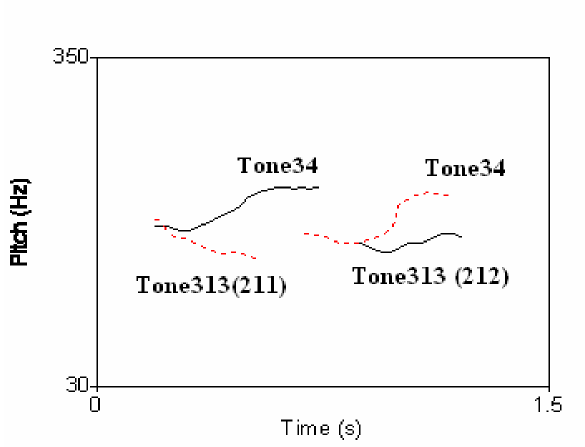


Figure 4.3: Pitch contour of Tone7[34] in WI and WF by Female_1
***[kʰɔɪ]34_[tʰɛʊ]313* "at the beginning" (dotted line) vs.**
***[tunʰ]313_[kjɛʊ]34* "to fill and level up a ditch" (plain line)**

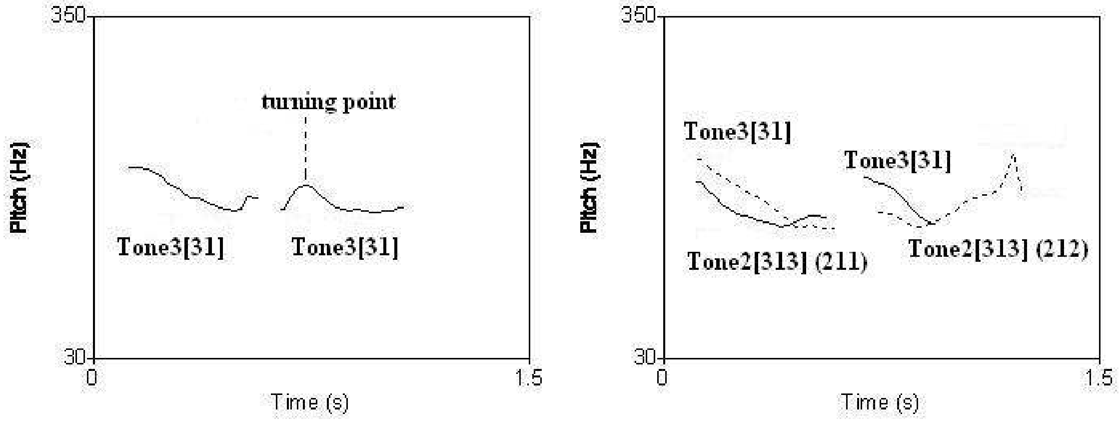
4.3.2 Falling Tones: Tone3[31] and Tone4[53]

The two falling tones, Tone31 and Tone 53, however, performed quite differently from Tone1[33], Tone2[313], and Tone7[34]. Table 4.6 shows the group statistics and the results of *t*-test. The results of *t*-test in Table 4.6 showed that all the parameters of Tone3[31] in WI were quite different from those in WF. The average pitch value of BP, EP, Peak, and Valley were lower in WF than in WI, which might be resulted from the effect of declination, which was "a probably universal and clearly phonetic tendency to gradually lower pitch across an utterance" (Yip, 2002, p. 12).

Table 4.6: Group statistics of Tone3[31] and the results of *t*-test

Parameters	Position	N	Mean	SD	t(310)	Sig. (2-tailed)
BP (Hz)	WI	168	187.81	54.31	2.0672	<.05
	WF	144	175.63	48.89		
EP (Hz)	WI	168	148.83	47.84	4.4316	
	WF	144	127.07	37.10		
Peak (Hz)	WI	168	188.24	54.24	2.1083	
	WF	144	175.83	48.92		
Valley (Hz)	WI	168	147.24	46.38	4.5720	
	WF	144	125.51	35.82		
Mean_F0 (Hz)	WI	168	166.38	47.53	3.3359	
	WF	144	149.74	39.24		
DU (ms)	WI	168	247.63	92.64	4.2717	
	WF	144	206.23	75.90		
Slope (Hz/ms)	WI	168	-0.17	0.08	5.9550	
	WF	144	-0.24	0.12		

For duration, we found that final lengthening effect was not evident in Tone3[31]. On the contrary, this tone was shorter in WF position, $t(310)=4.2717$, $p<.05$. As for its slope, unlike ST-Tone1[33] (Tone7[34]) in WI, it was steeper in WF than in WI, $t(310)=5.9550$, $p<.05$, which was an evidence of an abrupt fall at the end of the utterance. To conclude, in WI, Tone3[31] was higher in its average pitch, shorter in duration, flatter in slope than it was in WF position. Pitch contours of Tone3[31] in different prosodic positions were shown in Figure 4.4.



(a) *[t^{h}jam]31_[t^{h}jam]31* "be tired"

(b) *[t^{h}o]31_[tɕ^{h}jɛn]313* "ask for money" (dotted line) vs. *[p^{h}ɪn]313_[k ^{h}u]31* "poor" (plain line)

Figure 4.4: Tone3[31] in WI& WF by Female_1

These utterances were again uttered by Female_1. Figure 4.4 (a) showed the pitch contour of *[t^{h}jam]31_[t^{h}jam]31* "tired", within which the preceding tone and the following tone were exactly the same in syllable structure, phonemes, and tone. The two syllables, however, demonstrated different tonal contours. Note that there was a turning point at the onset of the second syllable. The F0 of the offset was raised so as to prepare for the following higher onset of the second syllable, and we found an F0 "peak" delay appearing in the onset of the second syllable due to inertia. The low offset of the first syllable was raised to approximate the following mid onset. The mid onset of the second syllable also had to start from where the first syllable ended.

The approximation of the pitch targets were proposed by Xu's (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001) Target Approximation model. Xu (2004) proposed that "at the core of the model (TA Model) is the assumption that phonological tone categories are not directly mapped onto surface phonetic patterns; rather, each tone is associated with an ideal pitch target that is articulatorily operable" (p. 771).

From Figure 4.4, we found this kind of target approximation phenomenon in both (a) and (b). Xu also found F0 peak delay in his TA model, which was shown in Figure 4.5.

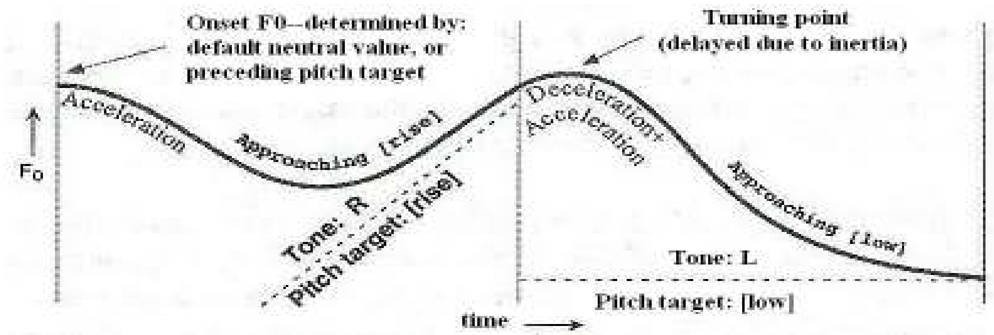


Figure 4.5: Dynamic and static targets and their implementation. The vertical lines represent syllable boundaries. The dashed lines represent underlying pitch target. The thick curve represents the F0 contour that results from asymptotic approximation of the pitch targets (Xu 2004, p. 774, Figure 9).[24]

In Figure 4.5, Xu (2004) proposed that "the seeming delay of the F0 peak often seen in connection with R (rise) resulted directly from implementing a [rise] when followed by a [low] or another target also with a low onset" (p. 774). This indicated that the F0 peak of the rising tone was delayed and it did not appear until the onset of the second syllable was uttered, which was due to inertia. However, in Figure 4.4 (a), it was a combination of two falling tones with a mid onset and a low offset. In this case, it was the F0 peak of the second falling tone that was delayed. Therefore, we did find an interesting mapping with Xu's Target Approximation model here in our example.

Unlike Tone3[31], Tone4[53] seemed to be impervious to the position where it was put as being shown in Table 4.7. As can be seen from this table, none of the measured parameters were significantly different, even though the average pitch height of Tone4[53] in WI was higher than that in WF position.

Table 4.7: Group statistics of Tone4[53] and the results of *t*-test

Parameters	Position	N	Mean	SD	t(214)	Sig. (2-tailed)
BP (Hz)	WI	72	221.44	69.01	1.7768	0.077
	WF	144	205.20	60.34		
EP (Hz)	WI	72	164.52	51.78	1.4681	0.144
	WF	144	154.16	47.40		
Peak (Hz)	WI	72	225.05	67.88	1.7598	0.080
	WF	144	208.94	61.11		
Valley (Hz)	WI	72	162.25	50.17	1.8118	0.071
	WF	144	150.25	43.60		
Mean_F0 (Hz)	WI	72	195.35	56.29	1.7484	0.082
	WF	144	182.20	49.89		
DU (ms)	WI	72	218.63	78.77	1.1913	0.235
	WF	144	203.96	88.44		
Slope (Hz/ms)	WI	72	-0.27	0.18	-0.8665	0.387
	WF	144	-0.24	0.21		

Xu (2004) found that the F0 contour in F is a "half fall" when followed by any other tone in a disyllabic sequence in Mandarin Chinese. "The Half F rule" termed by Xu (2004) was illustrated in (32) (p. 787).

(32) 51→53/_T

However, the "Half F rule" could not be applied to either Tone3[31] or Tone4[53] in

Ta-pu Hakka. If this rule could be applied to Tone4[53] in this language, we would have found that the falling slope should have been flatter in WI, which was just opposite in the case of Tone4[53]. As can be seen from Table 4.7, the slope of Tone4 was steeper in WI than in WF, though the difference was not statistically significant, $t(214)=-0.8665$, $p=0.387$.

Of the two falling tones in Ta-pu Hakka, only the high falling Tone4[53] will undergo tone sandhi when it is followed by Tone3[31], Tone4[53], Tone5[3], and Tone6[4]. Therefore, if there were any significant difference found, Tone4[53] would have already been changed into ST-Tone4 by then, which was discussed in Section 3.2.2.3. The fact that the T-scale of this high falling tone remained as [53] in any position under our investigation also proved that the "Half F rule" did not apply to Tone53. If this rule could be applied to Tone53, the T-scale should have been changed into Tone54 in WI position. We assume that there was also a "Half F rule" in Ta-pu Hakka, but it only happens when the high falling tone Tone4 is followed by falling tones or checked tones. Furthermore, this "Half F rule" might be the reason that triggered the sandhi rule of Tone4[53].

Figure 4.6 showed the pitch contours of Tone4[53] in WI and WF positions. As can be seen from this figure, the pitch contours in both positions were very alike, which again proved the validity of the statistical results.

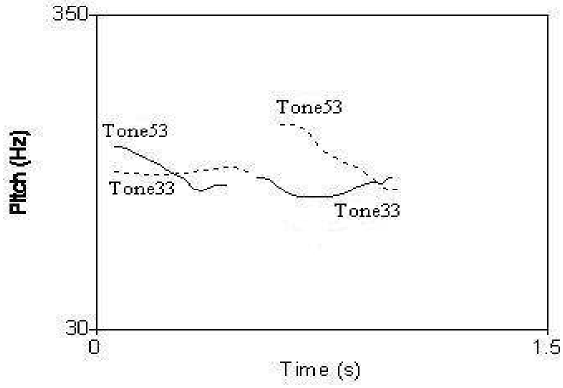


Figure 4.6:*Tone53 in WI& WF*
***[pʰɔŋ]33_[pʰaɪ]53* "big and luxurious (meal)" (dotted line) vs.**
***[pʰaʊ]53_[tʰɔŋ]33* "take a hot-spring bath" (plain line)**

4.3.3 Checked Tones: Tone5[3] and Tone6[4]

The group statistics and the results of *t*-test of Tone5[3] and Tone6[4] were shown in Table 4.8 and 4.9 respectively.

Table 4.8: Group statistics of Tone5[3] and the results of *t*-test

Parameters	Position	N	Mean	SD	t(305)	Sig. (2-tailed)
BP (Hz)	WI	164	179.88	55.07	-0.5810	0.562
	WF	143	183.54	54.92		
EP (Hz)	WI	164	163.68	49.64	-0.8589	0.391
	WF	143	168.92	57.12		
Peak (Hz)	WI	164	180.07	55.01	-1.0525	0.293
	WF	143	186.88	58.19		
Valley (Hz)	WI	164	160.92	47.99	-0.4638	0.643
	WF	143	163.57	52.18		
Mean_F0 (Hz)	WI	164	169.36	49.96	-1.0273	0.305
	WF	143	175.47	54.19		
DU (ms)	WI	167	111.88	53.38	3.6870	<.05
	WF	144	90.20	49.70		
Slope (Hz/ms)	WI	164	-0.16	0.11	2.3725	<.05
	WF	143	-0.21	0.22		

For Tone5[3], the results indicated that it was longer in WI position, *t*(305)=3.6870, *p*<.05. Tone5[3] in WF also showed a steeper slope, *t*(305)=2.3725, *p*<.05. That it has longer duration in WI and steeper slope in WF was exactly the same as Tone3[31], but all the other parameters showed no significant differences in different prosodic positions. Thus, we might be able to infer from this result that Tone3 and Tone5 were similar not only in their T-scale, [31] vs. [3], but also in the same distribution of longer duration and steeper slope. This might be able to explain why Tung (1995) and Chiang (1998 a&b) assigned this low checked tone with [32] or [31].

Table 4.9: Group statistics of Tone6[4] and the results of *t*-test

Parameters	Position	N	Mean	SD	t	df	Sig. (2-tailed)
BP (Hz)	WI	168	210.83	65.13	2.2205	310	<.05
	WF	144	194.76	62.07	2.2288		
EP (Hz)	WI	168	204.23	62.60	2.0616	310	<.05
	WF	144	190.38	54.93	2.0823		
Peak (Hz)	WI	168	211.81	64.99	1.0840	310	0.279
	WF	144	204.04	61.01	1.0893		
Valley (Hz)	WI	168	201.66	61.31	2.8783	310	<.05
	WF	144	182.60	54.63	2.9039		
Mean_F0 (Hz)	WI	168	206.85	62.72	1.8976	310	0.059
	WF	144	193.89	56.95	1.9117		
DU (ms)	WI	168	123.99	58.23	-4.1008	310	<.05
	WF	144	155.49	77.20	-4.0147		
Slope (Hz/ms)	WI	168	-0.06	0.07	-0.0938	310	0.925
	WF	144	-0.06	0.18	-0.0888		

Table 4.9 showed the group statistics and the results of the *t*-test of Tone6[4]. We found that the slope, the pitch value of the Peak, and the average pitch height were impervious to the influence of prosodic positions. Like Tone3[31], the pitch value of BP, EP, Valley were higher in WI than in WF.

However, the result of duration comparison showed that Tone6[4] was longer in WF than in WI, indicating a final lengthening effect, just like Tone1, Tone2, and Tone7. From the phenomenon of final lengthening effect and its flatter slope as comparing to Tone5[3], Tone6[4] also showed similar tonal variations like a level tone.

4.3.4 Discussion and Interim Summary

To sum up, the duration of a tone is shorter in WI than in WF except for that in Tone3[31], Tone4[53], and Tone5[3]. That is to say, the duration of a level or a rising tone is longer in WF than in SI, indicating the effect of final lengthening.

In regard with pitch height, both phonological theory and phonetic data showed that the beginning pitch of an utterance is generally higher, which is similar to "declination" phenomenon. To sum up, final-lengthening and declination were both found in Ta-pu Hakka, the same as Peng's (1997) finding in Southern-Min dialect. As for final lowering effect, only Tone1[33] will show such tendency that the pitch value of EP is lower than that of BP though it is in fact a level tone. Huang (2003) found that all the level tones in Mei-nung Ssu-hsien Hakka showed falling slope, only that the slope was flatter than that of falling tones.

Though we have some interesting findings in this section, we still do not have a clear picture whether the changes in all the measured parameters within each tone are due to the prosodic position the tone is positioned only or there might be some other contextual factors. We still do not know whether the influence on pitch changes is anticipatory or perseverative (carryover), either. Thus, we would like to investigate how tonal contexts, which are referred to as a compatible or a conflicting context, will affect the tonal variations.

4.4 Tonal Context Effect on Tonal Coarticulation

In this section, we first reexamined the definition of tonal contexts, namely a compatible or conflicting context. According to Xu's (1994) experimental design of investigating tonal coarticulation in compatible and conflicting contexts in Mandarin Chinese, the target tones in this section would be confined to rising tones and checked tones only. The typical rising tone in Ta-pu Hakka was Tone7[34]. The concave tone, Tone2[313], would also be investigated though it was more atypical. However, since there was a rising contour in a concave tone, we would also like to know if tonal contexts have any influence on this tone. As for the falling tones, both Tone3[31] and

Tone4[53] would be investigated. Note that, the checked tones, Tone32 and Tone4 will be excluded in the discussion of contextual tonal effect in this section because we have found that it was quite difficult for us to classify checked tones into either context.

4.4.1 Introduction to Tonal Contexts and Definitions Modified

Context effect on tonal coarticulation refers to the effect of tonal context where a tone is in, that is, a compatible context or a conflicting context. According to Xu's (1994) definition, a **conflicting context** is where "*the adjacent phonetic units have **identical** or **similar** values along the phonetic dimension*" and a **compatible context** is where "*the adjacent phonetic units have very different values*" phonetic contexts (in abstract). Since the target language he has been studying is mainly Mandarin Chinese, which has only four phonemic tones (excluding the neutral tone), the tonal combinations of disyllabic words or even trisyllabic words are very easy to be categorized into the two contexts that Xu defined.

However, there are seven phonemic tones in Ta-pu Hakka.[25] Consequently, the tonal combinations, even a disyllabic one, were much more complicated and hence difficult to be classified into these two combinations. For example, in Ta-pu Hakka, Tone4[53]_Tone2[313] was in compatible context because the offset value of Tone4[53] was identical with the onset value of Tone2[313]. As for Tone7[34]_Tone3[31], the adjacent pitch value was similar to each other, with only one-scale difference, and it should be considered to have a compatible context as well. However, when Tone2[313] was followed by Tone4[53], the combination was similar to Tone3[214]_Tone4[51] in Mandarin Chinese, which was classified into the conflicting context by Xu (1994) because he considered Tone3[214] as a low-level tone.[26]

Therefore, we hereby summarized the criteria of classifying the tonal combinations in terms of conflicting and compatible contexts. When the adjacent tonal scales were identical with or similar to each other (referring to one-scale difference), we would categorize this kind of tonal combination as having a ***compatible context***. If the adjacent tonal value had a two-scale difference or more, this combination would have a ***conflicting context***. Besides considering the adjacent tonal value, we needed to take the adjacent tonal contour into consideration. According to the findings in our pilot study, for tones in Ta-pu Hakka, we would categorize a combination of [fall]_[rise] or [rise]_[fall] into the third kind of context, which was termed as a ***contour compatible context*** in the present study. For example, the combination of Tone4[31]_Tone7[34] was an F_R combination, whose pitch contours was compatible in their direction. Therefore, Tone3[31]_Tone7[34] was considered as having the third type of tonal context, namely a contour compatible context. On the other hand, the combination of Tone4[31]_Tone1[33] would be considered as having a conflicting context.[27] Therefore, we decided to classify Tone3[31] followed by Tone7[34] as having a contour compatible context, while Tone3[31] followed by Tone1[33] should be in a conflicting context.

After defining the three kinds of tonal contexts, the categorization of the tonal combination in our disyllabic word stimuli was shown in Table 4.10.

Table 4.10: Tonal combinations classified into <u>three contexts</u>: conflicting, compatible and contour compatible. (No.= case number. Shaded combinations represent sandhi tones (ST); the others are non-sandhi tones.)[28]

Tone3[31]			Tone4[53]		
compatible	conflicting	contour	compatible	conflicting	contour
No.=24	No.=120	No.=72	No.=96	No.=48	No.=24
313_31	31_53	31_34	55_53	33_53	313_53
	31_313	55_31	53_313	31_53	
	31_31	35_31	53_33		
	31_33		53_34		
Tone7[35/34]			**Tone2[313]**		
compatible	conflicting	contour	compatible	conflicting	contour
No.=72		No.=72	No.=120	No.=24	No.=24
33_34		35_313	53_313	31_313	35_313
313_34		35_31	33_313		313_53
53_34		31_34	313_31		
			313_33		
			313_34		

When investigating the influence of tonal contexts on tonal coarticulation in the present study, the word inventory used was disyllabic words, which was different from Xu's (1994) study. Therefore, we would exclude the prosodic position effect in this section. That is, we grouped the combinations in Table 4.10 regardless of the positions of the tone. What was taken into consideration was the context that a tone was in, namely a compatible context, a conflicting context, and a contour compatible context.

Since there were three levels in the independent variable, One-way ANOVA was conducted to compare the means among the three groups. Post-hoc test (Bonferroni) was conducted to compare the means between every two groups. Furthermore, because of the unequal sample sizes, test of “homogeneity of variances” would be conducted first.

The results of the two falling tones would be discussed first in Section 4.4.2. Then the results of Tone7 would be discussed in Section 4.4.3. In Section 4.4.4, we would then discuss the findings in Tone2. A general discussion and a tentatively summary would be presented in Section 4.4.5.

4.4.2 Falling Tones: Tone3[31] and Tone4[53]

Table 4.11 showed the statistical results of the means of all the measured parameters and the results of One-way ANOVA. The shaded parameters meant that the test of homogeneity of variances was assumed. Thus, though significant differences of means were found in the pitch value of Valley, the slope, the duration, and the F0 peak alignment, only the results of the Valley and the F0 peak alignment were reliable.

Table 4.11: Tone3[31]—Descriptive statistics of the means in three contexts and the results of One-way ANOVA (com=compatible; con=conflicting; contour=contour compatible; SD=standard deviation)

Parameters	Context	N	Mean	SD	F(2, 213)	Sig.
BP	com	24	170.55	44.40	0.72	0.488
(Hz)	con	120	184.37	55.29		
	contour	72	182.70	47.34		
EP	com	24	128.96	43.13	2.74	0.067
(Hz)	con	120	145.45	47.33		
	contour	72	132.34	37.92		
Peak	com	24	170.71	44.34	0.75	0.475
(Hz)	con	120	184.83	55.29		
	contour	72	182.78	47.42		
Valley	com	24	126.06	40.49	3.17	<.05
(Hz)	con	120	144.04	45.83		
	contour	72	130.88	36.65		
Mean	com	24	149.39	39.22	1.65	0.195
(Hz)	con	120	163.57	47.48		
	contour	72	154.12	39.68		
Duration	com	24	208.00	71.77	3.94	<.05
(ms)	con	120	242.10	87.47		
	contour	72	209.49	87.16		
Slope	com	24	-0.21	0.13	14.45	<.05
(Hz/ms)	con	120	-0.17	0.09		
	contour	72	-0.25	0.11		
Peak_alignment	com	24	5.66	20.77	3.26	<.05
(%)	con	120	3.67	9.31		
	contour	72	0.61	2.33		

As can be seen from Table 4.11, the minimum pitch value of Tone3[31] was significantly different from each other, F(2, 213)=3.17, $p<.05$. The hierarchy of Valley was as follows: con>contour>com, indicating that the minimum pitch value of Tone3[31] was raised when it was in a conflicting context—when it was followed by Tone1, Tone2, Tone3, and Tone4. Note that Tone3[31] in a conflicting context was when it was in WI position. As for the compatible and contour compatible contexts, we found that Tone3[31] was almost in WF position, except for the combination of Tone3_Tone7. As a result, that Tone3[31] had the highest pitch value of Valley and the longest duration might be resulted from the prosodic position effect, which has been discussed in Section 4.3.2. As for slope, the Post-hoc test showed that in a contour compatible context, the slope was much steeper than in a conflicting context. Xu's (1994) study showed that the slope of the falling tone Tone4[51] in Mandarin was steeper in a compatible context than in a conflicting context. Comparing Xu's study with the findings in the present study, we could infer that the contour context was quite similar to the compatible context.

This result might raise the question as to why we did not investigate the effect of tonal context according to different prosodic positions. That is, a compatible context in WI or in WF respectively. However, when we looked into the tonal combinations shown in Table 4.10, we could see when Tone3[31] was in WI, there would be only two possible contexts, conflicting context and contour compatible context, and the sample number was also unequal. Therefore, we would wonder if classifying tonal combinations into the three contexts is a suitable way of investigating tonal variations in Ta-pu Hakka.

As for Tone4, we also found that when it was in WI, it would always be in a compatible context. On the other hand, it would be in the three contexts when it was in WF. Table 4.12 showed the results of Tone4[53] in the three contexts regardless of its prosodic positions.

Table 4.12: Tone4[53]—Descriptive statistics of the means in three contexts and the results of One-way ANOVA (com=compatible; con=conflicting; contour= contour compatible; SD=standard deviation)

Parameters	Context	N	Mean	SD	F(2, 213)	Sig.
BP	com	90	215.53	66.43		
(Hz)	con	48	207.69	66.23	0.28	0.758
	contour	24	217.44	58.38		
EP	com	90	161.02	49.42		
(Hz)	con	48	163.34	58.76	0.18	0.833
	contour	24	155.46	48.48		
Peak	com	90	218.45	65.88		
(Hz)	con	48	215.79	67.12	0.07	0.930
	contour	24	221.94	59.13		
Valley	com	90	158.74	48.69		
(Hz)	con	48	157.65	53.22	0.56	0.573
	contour	24	146.98	40.83		
Mean	com	90	190.38	54.68		
(Hz)	con	48	191.08	57.36	0.04	0.963
	contour	24	187.41	48.54		
Duration	com	90	209.95	82.21		
(ms)	con	48	207.10	97.41	0.02	0.981
	contour	24	210.04	73.32		
Slope	com	90	-0.26	0.16		
(Hz/ms)	con	48	-0.20	0.30	1.86	0.159
	contour	24	-0.30	0.22		
Peak_alignment	com	90	5.46	10.46		
(%)	con	48	14.03	18.63	5.63	<.05
	contour	24	6.01	18.75		

As can be seen from Table 4.12, only the means of F0 peak alignment was in normally distribution, and only the differences of F0 peak alignment were statistically significant, $F(2, 213)=5.63$, $p<.05$. In other words, F0 peak delay was found when Tone4[53] was in a conflicting context, where it was preceded by Tone1 and Tone3. The peak delay was surely resulted from inertia because the offset pitch value of its preceding tones was either in the mid register or in the low register. The onset of Tone4 was lowered (207.69 Hz from Table 4.12) in order to approximate its following non-high register onset. Other than the F0 peak alignment, there was not any parameters of Tone4[53] being influenced by the tonal context.

To sum up, Tone3[31] might show steeper slope in contour compatible context, which was similar to the compatible context in some way. However, Tone4[53] was more impervious to prosodic positions and tonal contexts. Detailed comparison of the findings with TA model would be discussed in Section 4.4.5.

4.4.3 Tone7[34]

For Tone7, it had a compatible context when preceded by Tone1, Tone2, or Tone4, and it had a contour compatible context when followed by Tone2, or Tone3, or preceded by Tone3. Among all the combinations that included Tone7, there were no combinations in a conflicting context being found. Note that whenever Tone7 was in a compatible context, it was always positioned in WF, whereas it was almost in WI (2 out of 3 cases) when it was in a contour compatible context. As a result, the differences found between the two tonal contexts might have been resulted from prosodic effect as well. Table 4.13 shoed the descriptive statistics and the results of the *t*-test.

Table 4.13: Tone7[34]—Descriptive statistics of the means in two contexts and the results of the *t*-test (com=compatible; con=conflicting; contour= contour compatible; SD=standard deviation)

T7	context	N	Mean	SD	t(142)	Sig.
BP	com	72	155.56	44.99	-0.8445	0.400
	contour	72	162.07	47.51		
EP	com	72	181.89	59.45	-1.1524	0.251
	contour	72	192.98	55.97		
Peak	com	72	190.46	60.25	-0.8832	0.379
	contour	72	199.20	58.44		
Valley	com	72	148.13	43.05	-1.0292	0.305
	contour	72	155.55	43.47		
Mean	com	72	169.55	49.28	-0.7346	0.464
	contour	72	175.52	48.36		
Duration (ms)	com	72	320.46	87.06	2.9239	<.05
	contour	72	276.94	91.48		
Slope (Hz/ms)	com	72	0.09	0.09	-2.5274	<.05
	contour	72	0.12	0.07		
Valley_alignment (%)	com	72	15.64	20.40	-0.4745	0.636
	contour	72	16.96	11.65		

As can be seen from this table, the duration of Tone7[34] was much longer when it was in a compatible context, in which it always appeared in WF. Therefore, the longer duration might be owing to the final lengthening effect, instead of the influence of the tonal context. Furthermore, we also found that the slope of Tone7[34] was steeper in a contour compatible context, in which it was in WI in two of the three combinations. Therefore, the steeper slope of Tone7[34] might also be resulted from the influence of prosodic positions. Note that in this table, the standard deviations of duration and slope means were very large, and the reason might be the fact that Tone7 appeared both in WI and WF positions when it was in a contour compatible context. The prosodic position would cause different tonal variations in this tone.

As a comparison with Xu's (1994) finding that both falling and rising tones in Mandarin have steeper slope in a compatible context, Tone7[34] in Ta-pu Hakka did not show this tendency. On the contrary, the slope of Tone7[34] was steeper in a contour compatible context, which would be considered as a conflicting context by Xu (personal communication, June 21, 2007). So far, we found that classifying tonal combinations of disyllabic words into tonal contexts might not be able to explain the tonal variations found in Ta-pu Hakka.

4.4.4 Tone2[313]

Tonal combinations with Tone2 were mostly in a compatible context—5 out of 7 combinations. Note that only the data of the F0 valley alignment in the three groups were normally distributed, indicating that the statistical results of this parameter were more reliable.

Table 4.14: Tone2[313]—Descriptive statistics of the means in three contexts and the results of One-way ANOVA (com=compatible; con=conflicting; contour= contour compatible; SD=standard deviation)

T2		N	Mean	SD	F(2, 189)	Sig.
BP	com	120	140.09	49.05	0.62	0.538
	con	24	134.61	47.09		
	contour	48	147.31	49.69		
EP	com	120	132.34	47.35	0.95	0.387
	con	24	144.49	55.39		
	contour	48	128.10	44.88		
Peak	com	120	145.88	51.55	0.11	0.895
	con	24	147.40	55.06		
	contour	48	150.04	50.70		
Valley	com	120	120.81	40.17	0.51	0.604
	con	24	120.82	36.25		
	contour	48	114.34	35.81		
Mean	com	120	130.55	42.33	0.07	0.934
	con	24	131.25	42.74		
	contour	48	128.16	38.58		
Duration (ms)	com	120	244.83	109.15	2.60	0.077
	con	24	304.08	118.75		
	contour	48	264.29	140.90		
Slope (Hz/ms)	com	120	-0.03	0.11	7.98	<.05
	con	24	0.03	0.05		
	contour	48	-0.07	0.12		
Valley_alignment (%)	com	120	58.54	33.71	11.44	<.05
	con	24	28.59	24.23		
	contour	48	66.04	31.24		

Post-hoc test (Bonferroni) showed that the differences of F0 valley alignment between compatible and conflicting contexts were statistically significant, $p<.05$. As can be seen from this table, the F0 valley of Tone7 appeared in the early portion (28.59%) of the syllable. In this case, Tone7 was preceded by a falling tone, Tone3[31]. When it was in a compatible context, where its onset or offset T-scale was identical with its adjacent tone, the F0 valley appeared averagely in 58.54% of the syllable duration. On the other hand, we also noticed that the standard deviation of F0 valley alignment in a compatible context was very large because there were more possible variations in this context. In other words, Tone7, when in a compatible context, might be in WI or WF, and it was also adjacent to different tone types—rising, falling, or level tones.

To sum up, we suggested that the tonal variations in Ta-pu Hakka might be more related to the neighboring tones with regard to their pitch contour and pitch height. Pitch contours here could be termed as the dynamic pitch target, [rise], [fall], and [level]; pitch height could be termed as the static pitch target, [high], [mid], and [low] (Xu, 1999, 2004).

4.4.5 Discussion and Interim Summary

From the results shown from 4.4.2 to 4.4.4, the tonal variations in Ta-pu Hakka did not show a clear pattern via the classification of different tonal contexts. We could only tentatively summarize that Tone3[31] shows a steeper slope in a compatible and contour compatible context. Thus, we may be able to infer from this result that the contour compatible context is very similar to compatible context and Tone3[31] in these two contexts shows similar tonal variations. As for Tone4[53], this tendency is not evident because the results indicate that Tone4[53] is possibly impervious either to the tonal contexts or to the prosodic positions.

However, we do find an interesting phenomenon that the offset of the first syllable and the onset of the second syllable seem to approximate to each other. Xu's (2004) Target Approximation model (TA model) stipulates this kind of approximation between targets as illustrated in Figure 4.7.

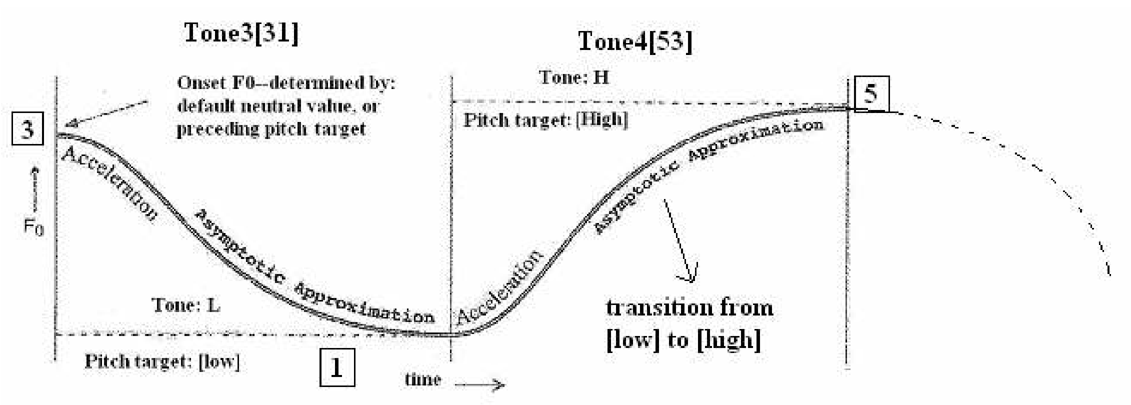


Figure 4.7: A schematic sketch of the TA model. The vertical lines represent syllable boundaries. The dashed lines represent underlying pitch targets. The thick curve represents the F0 contour that results from articulatory implementation of the pitch targets. (This figure was modified to meet our need) (Xu, 2004, p. 771)[29]

For example, when Tone4[53] is preceded by Tone3[31], the onset of Tone4[53] was [high], and the preceding Tone3[31] has a [low] offset. As a consequence, the articulatory implementation of the [low] pitch target creates a transition contour from [low] to [high], and hence the peak of Tone4[53] is delayed because of inertia.

As was mentioned in Section 4.4.1, the tonal combinations of disyllabic words in Ta-pu Hakka are far more complicated than those in Mandarin. Therefore, using the two tonal contexts may not be a very good criterion of investigating how tones interact with each other in Ta-pu Hakka. From the findings so far, we suggest that it might be the adjacent tones that will affect the tonal variations in Ta-pu Hakka. Therefore, in the coming section, we will investigate tonal variations of a tone when preceded or followed by different tones.

4.5 Adjacent Tone Effect on Tonal Coarticulation

In this section, we investigated how the tones influenced each other in different positions. We would like to investigate what kind of tonal variation would be caused by its adjacent tone. In this section, we will divide our findings into two sub-sections. Section 4.5.1 and 4.5.2 would discuss the carryover effect we found in level, rising, concave, high falling, and high checked tones. In Section 4.5.3 and 4.5.4, we would discuss the anticipatory effect found in falling tones and checked tones. Afterward, a general discussion and summary would be presented in Section 4.5.5.

4.5.1 Carryover Effect

4.5.1.1 Tone1[33]

All the measured parameters of Tone1[33], when positioned in WI position, were not significantly influenced by its following tones. On the other hand, the slope of

Tone1[33] is influenced by its preceding tone when it was in WF position. The result of one-way ANOVA was shown in Table 4.15, and the descriptive statistics of the mean slope was shown in Table 4.16. The Post-hoc test (Bonferroni) showed that the slope of Tone1[33] was much steeper when preceded by Tone5[3] or Tone6[4] than by Tone3[31], *p*<.05. Thus, the result suggested that a level tone preceded by a checked tone showed a steeper falling slope.

Table 4.15: One-way ANOVA: Tone33 in WF

Parameters	F(5, 138)	Sig.
BP_F0 (Hz)	0.1764	0.971
EP_F0 (Hz)	0.0970	0.992
PEAK_F0 (Hz)	0.1734	0.972
VALLEY_F0 (Hz)	0.0860	0.994
MEAN_F0 (Hz)	0.0829	0.995
DURATION (ms)	1.7635	0.124
SLOPE (Hz/ms)	4.0009	<.05
Post-hoc test (Bonferroni)	3 _33 vs. 31_33 4 _33 vs. 31_33	<.05

Table 4.16: Tone33 in WF—Mean slope when preceded by different tones

Preceding Tone	Case No.	Mean	Std. Deviation
Tone1[33]	24	-0.0301	0.016
Tone2[313]	24	-0.0328	0.045
Tone3[31]	24	-0.0233	0.025
Tone4[53]	24	-0.0391	0.022
Tone5[3]	24	-0.0504	0.029
Tone6[4]	24	-0.0521	0.022
Total	144	-36.296	29.442

Figure 4.8 showed an example of the pitch contours when Tone1[33] was preceded by all the tones except for Tone7[34]. The pitch contours were extracted from one of the utterances by Female_2. As can be seen from the pitch contours, the slope of Tone1[33] when preceded by either of the two checked tones (red lines) was a little steeper than when preceded by other fall tones. In fact, the steeper slope was not easy to compare only by observing the pitch contours shown in this figure because the differences between slope values were very small, and the statistical results shown in Table 4.16. should be used as references.

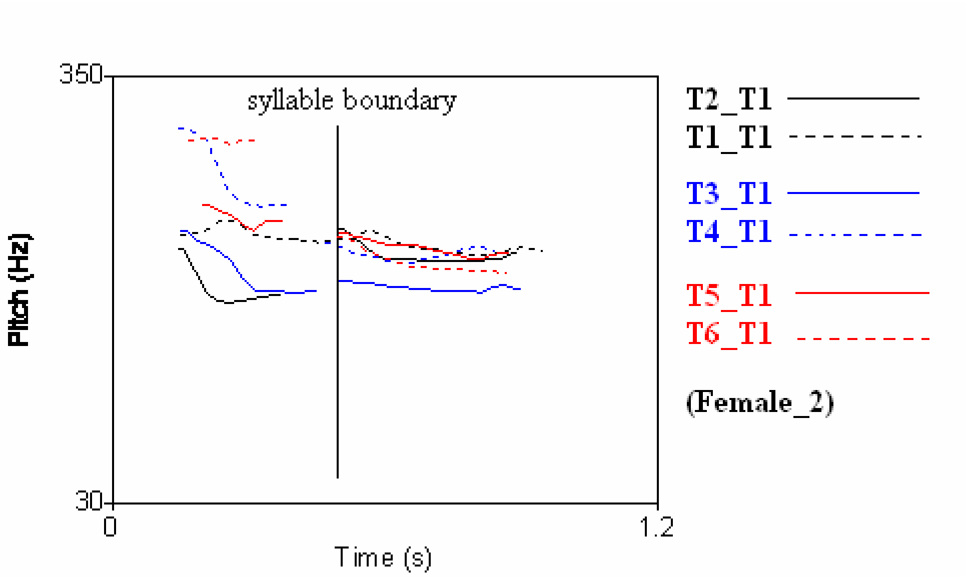


Figure 4.8: Pitch contour of Tone1[33] preceded by six tones in WF position.

4.5.1.2 Tone2[313]

The most special point about Tone2[313] was the alignment of the F0 valley, which indicated the temporal point at which the minimum pitch appeared in the syllable. This pitch valley alignment indicated the dipping characteristics in level or rising tones. As can be seen from Table 4.17, the result of one-way ANOVA showed that only the F0 valley alignment of Tone2[313] was influenced by its adjacent tone. The average F0 valley alignment of Tone2[313] was shown in Table 4.18.

Table 4.17: One-way ANOVA: Tone2[313] in WF

Parameters	F(5, 138)	***Sig.***
BP_F0 (Hz)	0.6565	0.657
EP_F0 (Hz)	0.2604	0.934
PEAK_F0 (Hz)	0.1582	0.977
VALLEY_F0 (Hz)	0.4980	0.777
MEAN_F0 (Hz)	0.2015	0.961
DURATION (ms)	0.6085	0.694
SLOPE (Hz/ms)	1.6251	0.157
F0 Valley Alignment (%)	3.2299	<.05
Post-hoc test	31_313 vs. 34_313	<.05

Table 4.18: Ton2[313] in WF—Mean F0 valley alignment preceded by different tones

Preceding tone	Case No.	Mean (%)	Std. Deviation
Tone1[33]	24	36.33	27.19
Tone3[31]	24	28.59	24.23
Tone4[53]	24	46.21	33.42
Tone5[3]	24	36.84	24.97
Tone6[4]	23	50.74	30.74
Tone7[34]	24	57.47	32.30
Total	143	42.64	30.13

The Post-hoc test indicated that the F0 alignment of Tone2[313] was shifted backward when preceded by the rising Tone7[34]. When preceded by Tone3[31], Tone2[313] became more like a rising tone with the F0 Valley appearing at about 28.6% of the syllable length. On the other hand, the F0 valley alignment was shifted to the middle of the syllable at 57.47% when Tone2[313] was preceded by a rising tone Tone7[34], indicating that the dipping characteristic appeared in the middle of the syllable. Figure 4.9 presented the pitch contours of Tone2[313] when preceded by Tone7[34] and Tone3[31]. As can be seen from this figure, the minimum pitch of the tonal combination 34_213 shifted backward comparing to the F0 valley alignment appearing in the 31_213 combination. This result indicated that the tonal shape of Tone2[313] was influenced by the tone type, i.e., [rise] or [fall], of its neighboring tone. When we again examined the data in Table 4.18, we found that the tonal shape of Tone2[313] was influenced by the offset pitch value of its preceding tones.

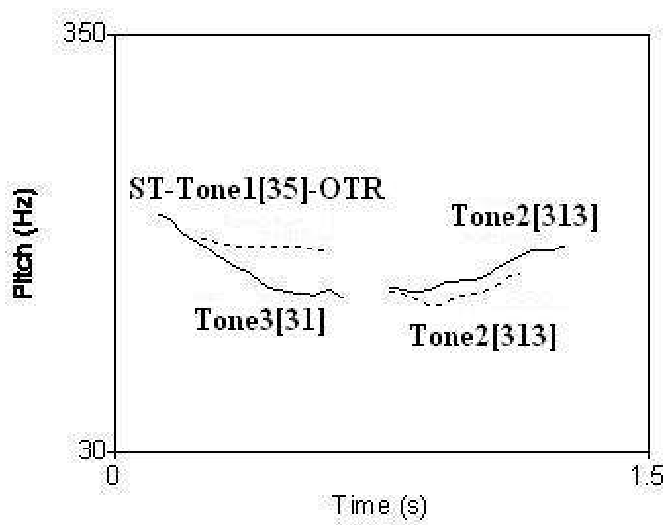


Figure 4.9: Pitch contour of Tone2[313] in WF position following ST-Tone1[35] and Tone3[31] (Female_2). ***[kʰɔɪ]34_[tʰɛʊ]313*** **"at the beginning" vs.** ***[tsʰaɪ]31_[tʰɛʊ]313*** **"a good sign".**

In order to test our hypothesis that the tonal shape of Tone2[313] would be influenced by the offset pitch value of its preceding tones, we divided the offset values of the tones in Ta-pu Hakka into three groups: high offset, mid offset, and low offset. One-way ANOVA was conducted to compare the means among the three groups, and the result was shown in Table 4.19. The result of One-way ANOVA indicated that the slope and F0 valley alignment of Tone2[313] were influenced by the register of the offset F0 of its preceding tone.[30] The descriptive statistical results of slope and F0 valley alignment in three groups were shown in Table 4.20. Groups in shade represented those reached significant level in the Post-hoc test.

Table 4.19: One-way ANOVA: Tone2[313] in WF, preceded by tones with different offset: high, mid, low.

Parameters	F(5, 138)	***Sig.***
BP_F0 (Hz)	1.1327	0.325
EP_F0 (Hz)	0.4194	0.658
PEAK_F0 (Hz)	0.2389	0.788
VALLEY_F0 (Hz)	0.6847	0.506
MEAN_F0 (Hz)	0.0376	0.963
DURATION (ms)	0.3787	0.685
SLOPE (Hz/ms)	3.5739	<.05
F0 Valley Alignment (%)	6.9055	<.05
Post-hoc test	**slope**: high vs. mid **F0 valley alignment**: high vs. mid. vs. low	<.05

As can be seen from Table 4.20, the average slope of Tone2[313] when it was preceded by tones with high offset register, such as Tone6[4] and Tone7[34], became negative. The result indicated that a tone with high offset might raise the onset pitch value of Tone2 and hence made it more like a falling tone.

Table 4.20: Mean slope and F0 valley alignment of Tone2[313] when preceded by tones with different offset register

	offset register	Case No.	Mean	Std. Deviation
SLOPE (Hz/ms)	high_offset	47	-0.0872	0.3667
	mid_offset	72	0.0154	0.1063
	low_offset	24	0.0298	0.0491
	Total	143	-0.0159	0.2283
F0 Valley Alignment (%)	high_offset	47	54.18	31.39
	mid_offset	72	39.79	28.71
	low_offset	24	28.59	24.23
	Total	143	42.64	30.13

Xu (2004) proposed three types of L variations in Mandarin. One type of the L variations was stated by Xu (2004) that "when syllable 1 carries different tones, L in syllable 2 has rather different onset F0, which is virtually determined by the offset F0 of syllable 1" (p. 786).

In order to see whether the onset of Tone2[313] in WF position was correlated with the offset value of its preceding tone, a Pearson correlation coefficient was conducted. The result showed that there were positive correlation between the onset of Tone2[313] and the offset of its preceding tone, $r(142)=.08$, $p<.01$. The correlation between onset of Tone2[313] and offset of its preceding tones was shown via the scatterplot in Figure 4.10.

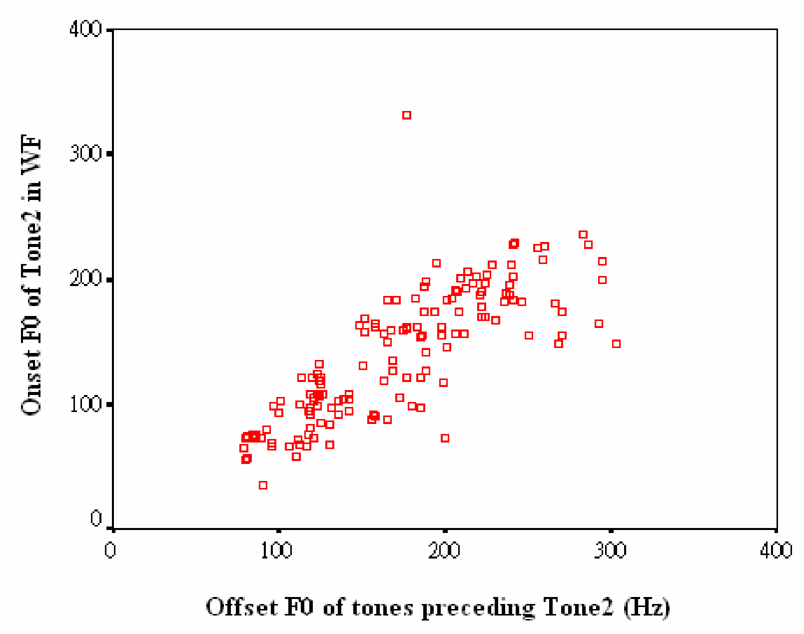


Figure 4.10: Scatterplot of the correlation between onset F0 of Tone2 and offset F0 of its preceding tones.

The result of the Pearson correlation coefficient agreed to Xu's (2004) assertion that onset F0 of syllable 2 is virtually determined by the offset F0 of syllable 1. Thus, we could tentatively summarize that the third type of L variations in Mandarin found by Xu (2004) was also evident in Ta-pu Hakka.

The above findings with regard to Tone2 in WF indicated that tonal variations in Tone2 could be regarded as a carryover effect. The positive correlation found between its onset F0 and the offset of its preceding tone also suggested that this effect was a kind of assimilation. Furthermore, the tonal shape of Tone2 in WF was also influenced by the offset register of its preceding tones.

4.5.1.3 ST-Tone1[35] vs. Tone7[34]

In Chapter Three, we have mentioned that Tone7[34] was in fact a sandhi tone of Tone1 when in WI of disyllabic words and it was designated as ST-Tone1[35], with original T-scale [35]. When this tone was in WI, there were only three possible tones following it—Tone2[313], Tone3[31] and Tone[3]. After conducting One-way ANOVA to test whether the following tones had any impact on ST-Tone1[35], there were no significant differences found in all the measured parameters. Possible explanations might be inferred from the results in 4.5.1.2. ST-Tone1[35] was not affected by its following tones probably because the three tones all began with a mid onset.

On the other hand, when Tone7[34] was positioned in WF position, it was influenced by its preceding tone, but the only parameter that was affected was duration. The result of one-way ANOVA was shown in Table 4.21 and the mean of duration in different groups was shown in Table 4.22. However, the Post-hoc test showed that duration of Tone7[34] when preceded by one tone was not significantly different from another.

Table 4.21: One-way ANOVA: Tone7[34] in WF

Parameters	F(5, 138)	*Sig.*
BP_F0 (Hz)	0.3259	0.897
EP_F0 (Hz)	0.2461	0.941
PEAK_F0 (Hz)	0.2726	0.927
VALLEY_F0 (Hz)	0.6009	0.699
MEAN_F0 (Hz)	0.2550	0.937
DURATION (ms)	3.0920	<.05
SLOPE (Hz/ms)	0.2970	0.914
F0 Valley Alignment (%)	0.2161	0.955
Post-hoc test	none	

Table 4.22: Tone7[34] in WF—Mean duration when following different tones

Preceding tone	N	Mean (sec)	Std. Deviation
Tone1[33]	24	348.67	86.60
Tone2[313]	24	333.21	85.98
Tone3[31]	24	345.42	83.59
Tone4[53]	24	279.50	75.85
Tone5[3]	24	345.79	78.26
Tone6[4]	24	297.42	79.79
Total	144	325.00	84.71

As we have discussed in 4.5.1.2, the onset F0 of Tone2[313] was correlated with the offset F0 of its preceding tones. From the results shown in Table 4.21 and 4.22, we found that Tone7[34] was in fact not influenced by its preceding tones to a great extent in duration. In order to investigate whether there was also a correlation between the onset F0 of Tone7[34] and the offset F0 of its preceding tones, a Pearson correlation coefficient was carried out. The result also showed that there was a positive correlation between the two variables, $r(140)=0.843$, $p<.01$. The correlation was shown in the scatterplot in Figure 4.11. The correlation shown in this figure indicated that the offset F0 of the preceding tone and the onset F0 of Tone7[34] was positively correlated.

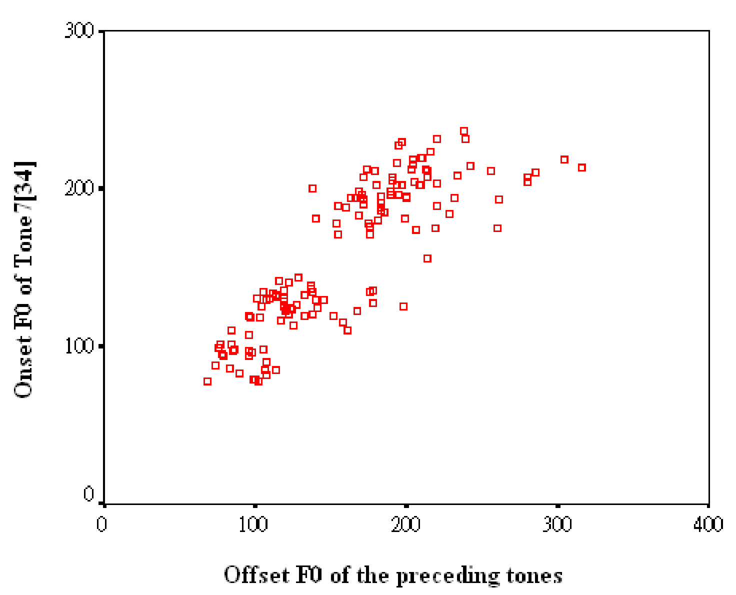


Figure 4.11: Scatterplot of the correlation between the onset F0 of Tone7[34] and the offset F0 of its preceding tones.

After we found that the correlation between adjacent pitch targets were highly correlated, we further conducted a Pearson correlation coefficient on Tone1[33] and the same positive correlation was also found, $r(143)=0.817$, $p<.01$. The result indicated aht the onset F0 of Tone1[33] was also positively correlated with the offset F0 of its preceding tones. To sum up, we have found that tonal variations in Tone1[33], Tone2[313], and Tone7[34] showed carryover assimilation effect. We would further investigate whether falling tones and checked tone would be influenced by their preceding tones.

4.5.1.4 Tone4[53]

For falling and checked tones, only Tone4[53] and Ton6[4] were found to be influenced by their preceding tones. Tone4[53] was influenced by its preceding tone, but the only parameter that was affected was F0 peak alignment, indicating the temporal point at which the peak F0 appeared in a syllable. Tone4[53] is a high falling tone, and its peak F0 should appear near the onset of the syllable. We assume that if the F0 peak alignment is shifted backward, the phenomenon will be termed as peak delay as defined by Xu (2004).

The result of one-way ANOVA was shown in Table 4.23. The Post-hoc test indicated that F0 peak alignment of Tone4[53] between any two tones showed no significant differences.

Table 4.23: One-way ANOVA: Tone4[53] in WF

Parameters	F(5, 138)	***Sig.***
BP_F0 (Hz)	0.3482	0.883
EP_F0 (Hz)	0.8414	0.523
PEAK_F0 (Hz)	0.6822	0.638
VALLEY_F0 (Hz)	0.4448	0.816
MEAN_F0 (Hz)	0.7232	0.607
DURATION (ms)	0.4273	0.829
SLOPE (Hz/ms)	0.8938	0.487
F0 Peak Alignment (%)	3.0708	<.05
Post-hoc test	none	

The mean F0 peak alignment of Tone4[53] when preceded by different tones was shown in Table 4.24 and the mean plot was presented in Figure 4.12.

Table 4.24: Tone4[53] in WF—Mean F0 peak alignment when preceded by different tones

Preceding tone	N	Mean (%)	Std. Deviation
Tone1[33]	24	13.86	21.11
Tone2[313]	24	6.01	18.75
Tone3[31]	24	14.19	16.23
ST-Tone4	24	1.69	2.71
Tone5[3]	24	3.91	10.47
Tone6[4]	24	5.61	10.67
Total	144	7.54	15.19

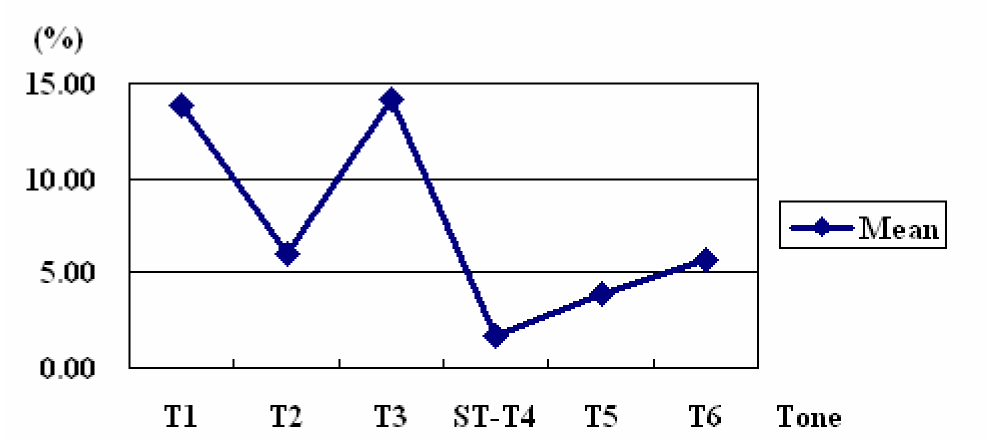


Figure 4.12: Mean plot of F0 peak alignment of Tone4[53] preceded by different tones

Though the Post-hoc test showed no significant differences between any two tones, we could still infer from Table 4.24 and Figure 4.12 that the F0 peak appeared almost at the beginning point, 1.69%, of the syllable when preceded by ST-Tone4, which was given the T-scale [55] as its original phonological representation. When it was preceded by Tone3[31], which was a tone with a low offset, the F0 peak delay occurred because of inertia, which has been discussed in Section 4.4.5. This kind of peak delay also implied that the onset F0 of Tone4[53] was trying to approximate to the offset of its preceding syllable, indicating a carryover assimilation effect. In order to test the correlation between the onset F0 of Tone4[53] and the offset F0 of its preceding tone, a Pearson correlation coefficient was conducted. The result showed that there was a positive correlation between the two parameters, $r(143)=0.805$, $p<.01$. The correlation between the two parameters was shown in Figure 4.13. The relationship between Tone4[53] variations and the sandhi rule related to Tone4[53] would be discussed in Section 4.5.2.

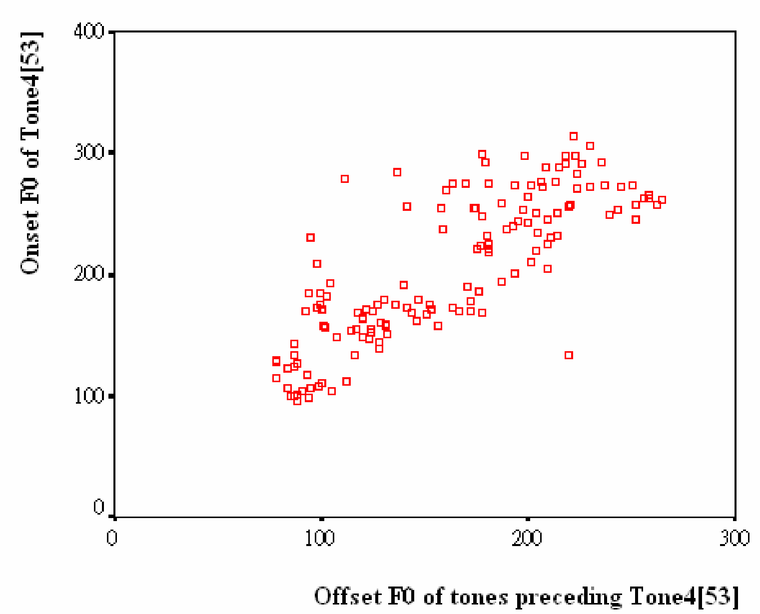


Figure 4.13: Scatterplot of the correlation between the onset F0 of Tone4[53] and the offset F0 of its preceding tones.

4.5.1.5 Tone6[4]

Tone6[4] was the only checked tone that was ever influenced by its preceding tone. The result of One-way ANOVA of Tone6[4] preceded by different tones was shown in Table 4.25. For Tone6[4], two parameters were significantly influenced by its preceding tones, slope and F0 peak alignment.

Table 4.25: One-way ANOVA: Tone6[4] in WF

Parameters	F(5, 138)	***Sig.***
BP_F0 (Hz)	0.5528	0.736
EP_F0 (Hz)	0.0365	0.999
PEAK_F0 (Hz)	0.1065	0.991
VALLEY_F0 (Hz)	0.4156	0.837
MEAN_F0 (Hz)	0.1576	0.977
DURATION (ms)	1.6800	0.143
SLOPE (Hz/ms)	2.2932	<.05
F0 Peak Alignment (%)	5.4400	<.05
Post-hoc test	**Slope**: 3_4 vs. 31_4 **F0 peak alignment**: T2, T3, ST-T4, T5, T6	<.05

The mean slope and mean F0 peak alignment of Tone6[4] when preceded by different tones was shown in Table 4.26. The mean plot of the slope would not be presented because the negative value was relatively small, but the mean plot of the F0 peak alignment was shown in Figure 4.14.

Table 4.26: Tone6[4] in WF—Mean slope and mean F0 peak alignment when preceded by different tones

Parameters	Preceding tone	N	Mean (%)	Std. Deviation
Slope (Hz/ms)	Tone1[33]	24	-0.06	0.12
	Tone2[313]	24	-0.04	0.22
	Tone3[31]	24	-0.13	0.19
	ST-Tone4[55]	24	-0.07	0.20
	Tone5[3]	24	0.04	0.17
	Tone6[4]	24	-0.08	0.12
	Total	168	-0.06	0.18
	Preceding tone	N	Mean (%)	Std. Deviation
F0 Peak Alignment (%)	Tone1[33]	24	31.73	34.48
	Tone2[313]	24	22.45	26.11
	Tone3[31]	24	19.74	28.78
	ST-Tone4[55]	24	16.77	21.60
	Tone5[3]	24	51.04	30.64
	Tone6[4]	24	18.14	20.73
	Total	168	26.65	29.54

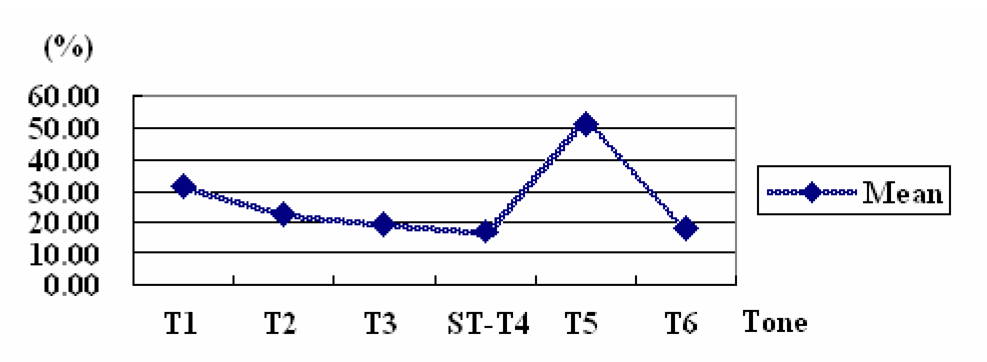


Figure 4.14: Mean plot of F0 peak alignment of Tone6[4] preceded by different tones

The result of Post-hoc test in Table 4.25 and the mean plot of F0 peak alignment of Tone6[4] in Figure 4.14 both showed that the peak delay occurred when Tone6[4] was preceded by the low checked tone Tone5[3]. The temporal point of peak F0 in the syllable when preceded by Tone5[3] could range from 20% to 80% of the syllable, with the average point at 51.04%. Thus, idiosyncratic difference might exist in different items. The result indicated that the onset F0 of Tone6[4] might be lowered to reach its preceding pitch target [mid], so the peak would not appear until the transition was done.

The peak delay, which was due to inertia, might also be related to the correlation between the onset F0 of Tone6[4] and the offset F0 of its preceding tones. The result of the Pearson correlation coefficient showed that the two parameters were in significantly positive correlation, $r(143)=0.873$, $p<.01$. The positive correlation was illustrated via the scatterplot in Figure 4.15.

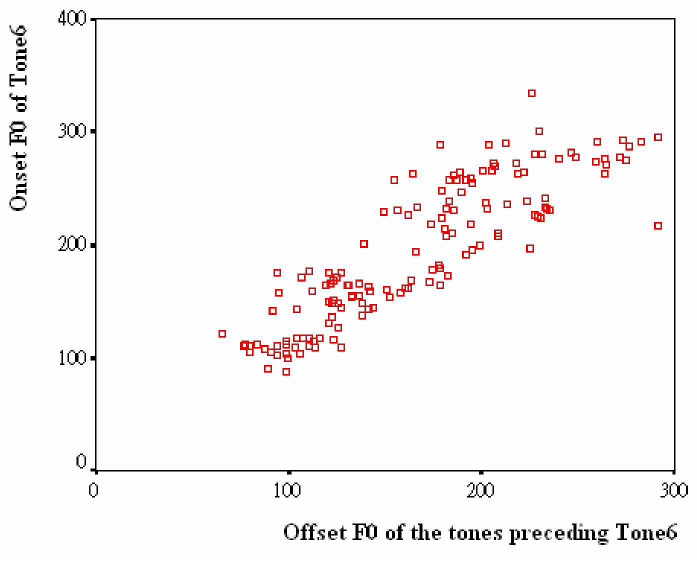
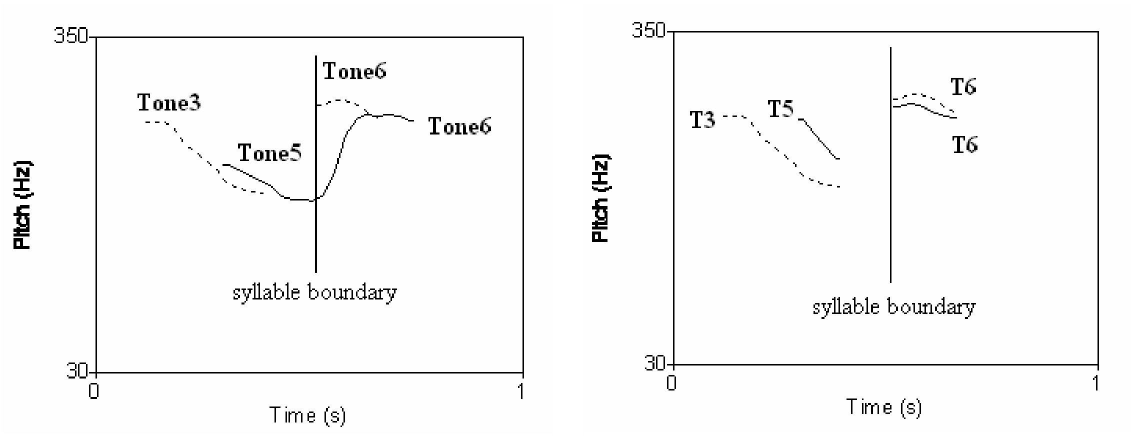


Figure 4.15: Scatterplot of the correlation between the onset F0 of Tone6[4] and the offset F0 of its preceding tones.

For slope, the result of Post-hoc test indicated that the slope of Tone6[4] was much steeper when it was preceded by Tone3[31] than by Tone5[3]. Two examples of pitch contours of Tone6[4] with different initial consonants when preceded by Tone5[3] and Tone3[31] was shown in Figure 4.16 (A) and (B).



(A) (B)

Figure 4.16: Mean plot of F0 peak alignment of Tone6[4] preceded by Tone3 and Tone5 with different syllable structures of Tone6. (A): *[kʰju]31_[hɛt]4* "to tug (at sth.) vs. *[tsʰak]_[ʒɔk]* "to buy Chinese herbal medicine according to a doctor's prescription"; (B): *[kʰju]31_[hɛt]4* "to tug (at sth.) vs. *[pʰʊk]3_[hɛt]4* "to place (sth.) upside down.

As can be seen in this figure, the reason why the slope of Tone6[4] was positive, 0.04 (SD=0.17), was that one of the four items with the tonal combination of Tone5_Tone6 had a voiced onset and the pitch value of the consonant was included. As can be seen in Figure 4.16(A), the slope of Tone6 in plain line showed a rising contour. As a consequence, the mean slope became positive because the slope of the rising contour was obviously larger than the falling contour. In order to minimize the microprosodic effect, voiced initials should have been excluded. However, in the present study, we believed that TBU should be associated with the whole syllable, and hence the pitch of the initial should be included as long as there were visible pitch contours. In fact, the voiced onset in the example, *[tsʰak]_[ʒɔk]* “to buy Chinese herbal medicine according to a doctor’s prescription”, showed the pitch transition from one target to another. Therefore, the rising contour of Tone6[4] should not be overlooked.

4.5.2 Discussion and Interim Summary of Carryover Effect

So far, the results found in all the sub-sections in Section 4.5.1 show that all tones are influenced by their preceding tones except for Tone3[31] and Tone5[3]. The results of prosodic effect in Section 4.4 suggest that the two tones in fact behave similarly in their slope and duration. The tonal variations found in these tones are a kind of carryover assimilation effect.

As for the parameters of tones in WF being influenced by their preceding tones, the influence is not pervasive in all the measured parameters. Significant differences are found only in the slope of Tone1[33], the duration of Tone7[34], the F0 valley alignment of Tone2[313], the F0 peak alignment of Tone4[53] and Tone6[4], and the slope of tone6[4]. A positive correlation between the onset F0 of the above tones in WF and the offset F0 of their preceding tones indicates that the carryover effect is assimilation.

The results of the other two tones, Tone3[31] and Tone5[3], would be discussed in Section 4.5.3. The two tones are found to be influenced by their following tones only, indicating an anticipatory effect.

4.5.3 Anticipatory Effect

In this section, we would discuss those tones that were influenced by their following tones, which indicated a kind of anticipatory tonal coarticulation. The tones that were influenced by their following tones were Tone3[31], Tone4[53], Tone5[3], and Tone6[4]. The results again suggested that falling tones and checked tones have similar patterns in tonal coarticulation.

4.5.3.1 Tone3[31]

When put in WF position, Tone3[31] was not influenced by its preceding tone. It was found to be influenced by its following tone when it was in disyllabic words. Table 4.27 showed the statistical result of One-way ANOVA, which compared all the measured parameters when Tone3[31] was followed by different tones. The mean slope of tone3[31] followed by different tones were shown in Table 4.28.

Table 4.27: ANOVA: Tone3[31] in WI, followed by different tones

Parameters	F(6, 161)	*Sig.*
BP_F0 (Hz)	0.0858	0.998
EP_F0 (Hz)	0.3660	0.900
PEAK_F0 (Hz)	0.0846	0.998
VALLEY_F0 (Hz)	0.3661	0.900
MEAN_F0 (Hz)	0.2223	0.969
DURATION (ms)	0.5037	0.805
SLOPE (Hz/ms)	2.5344	<.05
F0 Peak Alignment (%)	1.4580	0.196
Post-hoc test	31_34 vs. 31_33	<.05

Table 4.28: Tone3[31] in WI—Mean slope when followed by different tones

Following tone	N	Mean	Std. Deviation
Tone1[33]	24	-0.1324	0.0573
Tone2[313]	24	-0.1888	0.0699
Tone3[31]	24	-0.1529	0.0835
Tone4[53]	24	-0.1628	0.0935
Tone5[3]	24	-0.1670	0.0962
Tone6[4]	24	-0.1634	0.0739
Tone7[34]	24	-0.2134	0.0768
Total	168	-0.1687	0.0819

The Post-hoc test showed that the slopes of Tone3[31] when followed by Tone1[33] and Tone7[34] were significantly different, $p<.05$. From Table 4.28, we could see that Tone3[31] had a steeper slope when followed by Tone7[34] than by Tone1[33]. Tone3[31] followed by Tone1[33] or Tone7[34] would have a conflicting context according to Xu's definition. However, the slope of Tone3[31] when followed by the two tones showed significant differences in the two contexts. This might imply that the combinations of T3_T1 and T3_T7 should be considered as having different tonal contexts.

This incongruence in tonal variations within the same kind of tonal context also suggested that Tone3[31] was influenced by its neighboring tones respectively, rather than by tonal contexts. The slope of Tone3[31] was the steepest when followed by Tone7[34], a rising tone, but it was also very steeper when followed by Tone2[313], which could be considered as having an overall rising contour. Therefore, we assumed that the falling slope of Tone3[31] would be steeper when followed by a rising tone. In Section 4.4.1, we categorized Tone3_Tone7 combination into the third type of tonal context, that is, contour compatible context. In Section 4.4.2, we found that Tone3[31] had steeper slope in compatible and contour compatible contexts, indicating that the two contexts had similar effect on Tone3[31].

Figure 4.17 showed pitch contours of Tone3[31] when followed by seven tones, T1 to T7. Figure 4.18 showed pitch contours of Tone3[31] followed by Tone1[33] and Tone7[34]. As for Figure 4.17, we could see that the onset F0 of Tone3[31] was raised when it was in WI, and the offset F0 of Tone3[31] seemed to approximate to the onset of its following tones except when it was followed by Tone4[53] and Tone6[4].

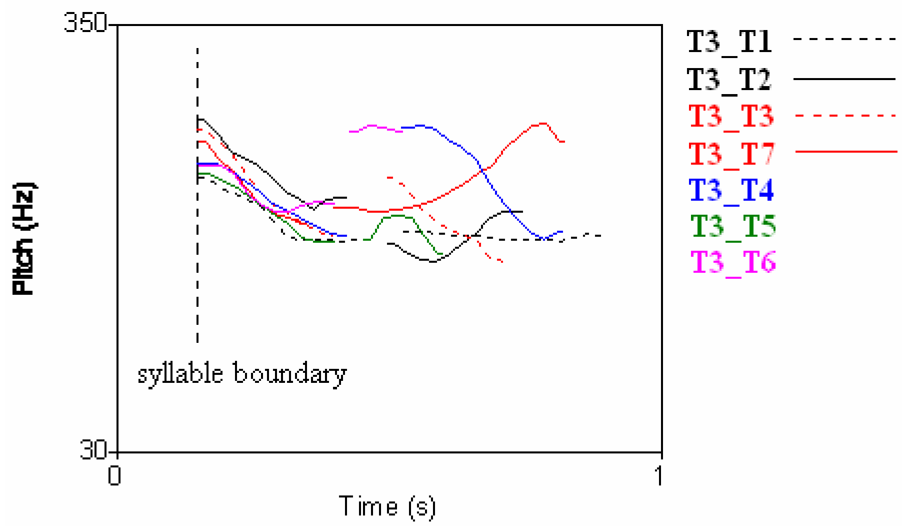


Figure 4.17: Pitch contours of Tone3[31] in WI position preceding 7 tones.

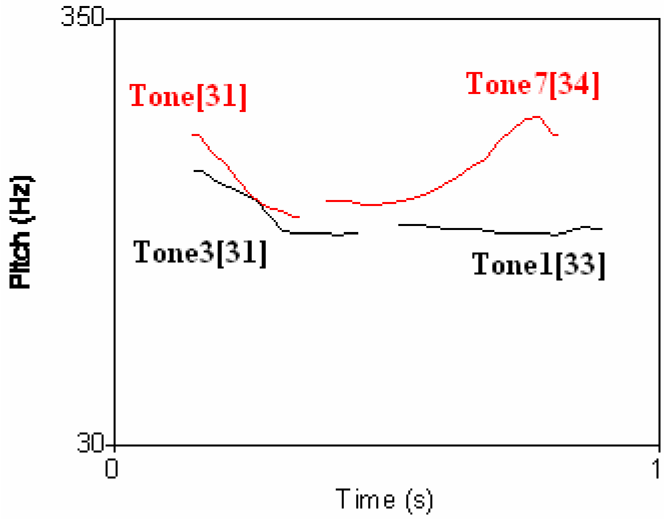


Figure 4.18: Tone3[31] followed by Tone1[33] and Tone7[34]--*[tʰo]31_[tɕʰɪn]33* "to marry a woman" vs. *[sɨ]31_[tɕʰja]34* "to drive a car"

In order to explore the correlation between the offset F0 of Tone3[31] and the onset F0 values of its following tones, Pearson correlation coefficients were carried out. The results indicated that the BP, EP, Peak, Valley, and average F0 of Tone3[31] were positively correlated with the onset F0 of its following tones. This result supported the postulation mentioned earlier that the EP of Tone3[31] would approximate to the offset F0 of the BP of its following tones.

4.5.3.2 Tone4[53]

Tone4[53], when positioned in WI, would undergo tone sandhi rules and turned ST-Tone4[55]-OTR when followed by Tone3[31], Tone4[53], Tone5[3] and Tone6[4]. Therefore, in this section, Tone4[53] was significantly influenced only by its following

Tone1[33], Tone2[313], and Tone7[34], which were all non-falling and non-checked tones. As for ST-Tone4[55], the anticipatory effect of this tone being affected by its following four tones would be discussed in Section 4.5.3.3.

As for the high falling Tone4[53], it was still the slope that was significantly influenced by its following tones. The results of one-way ANOVA were shown in Table 4.29. The average slopes of Tone4[53] when followed by the three tones were shown in Table 4.30.

Table 4.29: One-way ANOVA: Tone4[53] in WI

Parameters	F(2, 69)	***Sig.***
BP_F0 (Hz)	0.4061	0.668
EP_F0 (Hz)	0.5313	0.590
PEAK_F0 (Hz)	0.5847	0.560
VALLEY_F0 (Hz)	0.7239	0.488
MEAN_F0 (Hz)	0.0206	0.980
DURATION (ms)	0.3197	0.727
SLOPE (Hz/ms)	3.3904	<.05
F0 Peak Alignment (%)	0.3853	0.682
Post-hoc test	None	

Table 4.30: Tone4[53] in WI—Mean slope when followed by different tones

Following tone	N	Mean	Std. Deviation
Tone1[33]	24	-0.2355	0.1105
Tone2[313]	24	-0.3395	0.2524
Tone7[34]	24	-0.2222	0.1081
Total	72	-265.712	176.523

We could see that the falling slope of Tone4[53] was much steeper when it was followed by Tone2[313] than by Tone1[33] or Tone7[34], and the pitch contours were shown in Figure 4.19.

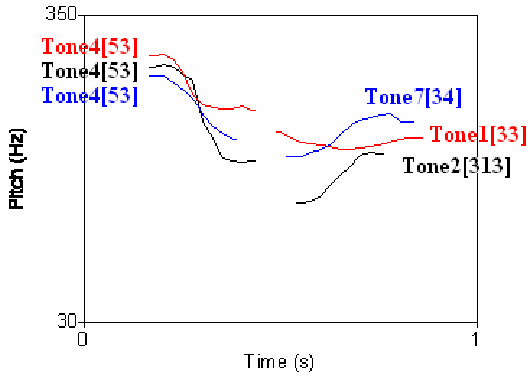


Figure 4.19: Pitch contour of Tone4[53] in WI position (*[pʰaɪ]53_[tʰɛu]313* "the way one acts and speaks"; *[tʰaɪ]53_[fɔŋ]33* "big wind"; *[tʰe]53_[ɕɪn]34* "a scapegoat")

As can be seen in Figure 4.19, the offset F0 of Tone4[53] seemed to approximate to the onset F0 of its following tones. A Pearson correlation coefficient was conducted and the results showed that the two parameters were positively correlated, $r(143)=0.856$, $p<.01$. The result indicated that the lower the onset F0 of the back tone, the lower the offset of the front tone. It also implied that the tonal coarticulation was a kind of anticipatory assimilation, or we might say that the offset of the front tone was trying to approximate its value to reach the target, which was the onset of its adjacent tone according to Xu's (2004) Target Approximation model.

When Tone4[53] was positioned in WF position as discussed in Section 4.5.1.4, its F0 peak alignment was influenced by its preceding tone. The interaction between tones showed a carryover assimilation effect. However, when it was in WI position, it was its slope that was affected by the following tones. The positive correlation between the offset F0 of Tone4[53] and the onset F0 of its following tones suggested that the coarticulation effect of Tone4[53] in WI was also an anticipatory assimilation effect, which was just the same as in the tonal variations found in Tone3[31].

4.5.3.3 ST-Tone4[55]-OTR

When Tone4[53] was in WI position of a disyllabic word, it would turn a sandhi tone [55], which was denoted with its original tonal representation, when followed by Tone3[31], Tone4[53], Tone5[3] and Tone6[4]. The results of One-way ANOVA and were shown in Table 4.31. The results showed that the slope and the F0 peak alignment were significantly influenced by the four following tones. The mean slope and mean F0 peak alignment were shown in Table 4.32.

Table 4.31: One-way ANOVA: ST-Tone4[55]-OTR in WI

Parameters	F(3, 92)	*Sig.*
BP_F0 (Hz)	0.014	0.998
EP_F0 (Hz)	0.346	0.792
PEAK_F0 (Hz)	0.017	0.997
VALLEY_F0 (Hz)	0.295	0.829
MEAN_F0 (Hz)	0.101	0.959
DURATION (ms)	1.522	0.214
SLOPE (Hz/ms)	6.558	<.05
F0 Peak Alignment (%)	5.682	<.05
Post-hoc test	**Slope**: 55_53 vs. 55_31 or 55_3 or 55_4 **F0 peak alignment:** 55_31 vs. 55_53 or 55_4	<.05

Table 4.32: Tone6[4] in WF—Mean slope and mean F0 peak alignment when preceded by different tones

Parameters	Preceding tone	N	Mean (%)	Std. Deviation
Slope	Tone3	24	-0.0532	0.0520
	Tone4	24	-0.1342	0.1254
	Tone5	24	-0.0436	0.0410
	Tone6	24	-0.0715	0.0644
	Total	96	-0.0756	0.0844
	Preceding tone	N	Mean (%)	Std. Deviation
F0 Peak Alignment	Tone3	24	35.07	36.71
	Tone4	24	6.82	17.02
	Tone5	24	18.40	27.19
	Tone6	24	10.11	17.81
	Total	96	17.60	27.80

The results of Post-hoc test indicated that the slope of ST-Tone4[55]-OTR was the steepest when it was followed by Tone4[53] than by Tone3[31], Tone5[3], or Tone6[4]. The temporal point at which the F0 peak appeared in a syllable was at about 35.07% (SD=36.71). However, when we looked into the average and standard deviations of this parameter, we found that the standard deviations were all so large that the statistical results might not be very reliable. As a result, only the slope would be discussed in detail. Figure 4.20 showed the pitch contour of ST-Tone4[55]-OTR produced by Female_3.

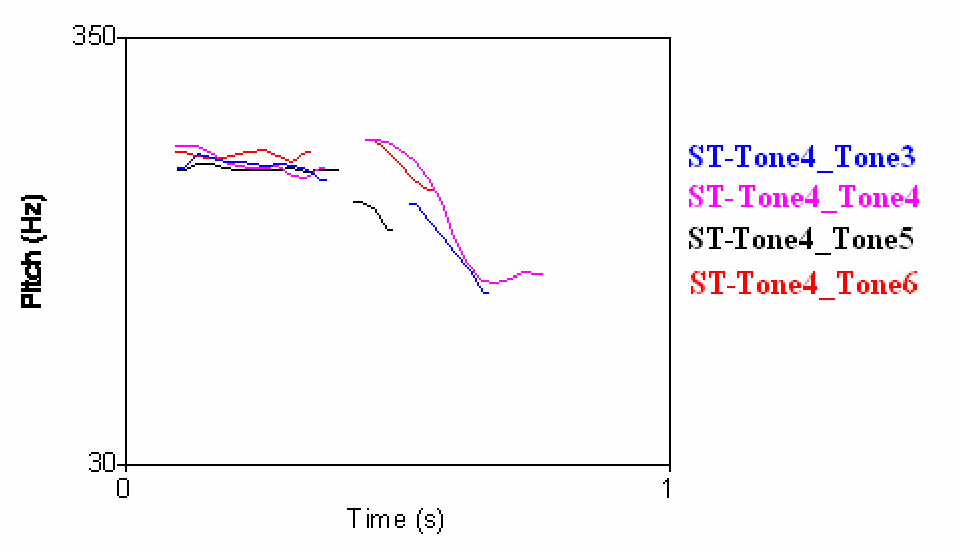


Figure 4.20: Pitch contours of ST-Tone4 followed by Tone3, Tone4, Tone5 and Tone6.

As can be seen from this figure, the falling slope when followed by Tone4[53] was a little steeper than by the other three tones. Furthermore, the offset F0 of ST-Tone4[55] seemed to approximate to the onset F0 of its following tones, which has been discussed in previous sections. A Pearson correlation coefficient was carried out, and the result showed that there was a positive correlation between the two parameters, $r(94)=0.923$, $p<.05$.

So far, we have found that there was a positive correlation between the offset F0 of the tones in WI and the onset F0 of those in WF. This positive correlation agreed to Xu's (2004) Target Approximation model. However, could this TA model be applicable to all the tonal variations found in Ta-pu Hakka? Some counterevidence would appear in the later sections.

4.5.3.4 Checked Tones

Checked tones are usually considered as shorter in duration. The result of *t*-test showed that the average duration of checked tone was significantly shorter than that of unchecked tones, $t(2014)=-30.256$, $p<.05$. As can be seen in Table 4.33, the average duration of the two checked tones was about 120.35 milliseconds, and that of the unchecked tones was about 254.71 milliseconds, about twice longer than checked tones.

Table 4.33: Duration comparison between checked tones and unchecked tones

	N	Mean (ms)	Std. Deviation
checked tone	624	120.35	102.23
unchecked tone	1392	254.71	64.29
		$t(2014)=30.256$, $p<.05$	

The results of One-way ANOVA on comparing means of all the measured parameters of Tone5[3] in WI position were shown in Table 4.34. We found that only the duration of Tone5[3] was significantly influenced by its back tone, $F(6, 158)=3.0088$, $p<.05$. Mean duration of Tone5[3] in WI followed by different tones was shown in Table 4.35.

Table 4.34: One-way ANOVA: Tone5[3] in WI

Parameters	F(6, 157)	*Sig.*
BP_F0 (Hz)	0.1267	0.993
EP_F0 (Hz)	0.0467	1.000
PEAK_F0 (Hz)	0.1270	0.993
VALLEY_F0 (Hz)	0.0447	1.000
MEAN_F0 (Hz)	0.0752	0.998
DURATION (ms)	3.0088	<.05
SLOPE (Hz/ms)	1.3252	0.249
F0 Peak Alignment (%)	1.0344	0.405
Post-hoc test	none	

Table 4.35: Tone5[3] in WI—Mean duration when followed by different tones

Following tone	N	Mean	Std. Deviation
Tone1[33]	23*	130.43	65.12
Tone2[313]	24	136.93	53.88
Tone3[31]	24	100.96	45.65
Tone4[53]	24	94.83	49.64
Tone5[3]	24	112.50	46.90
Tone6[4]	24	88.17	43.13
Tone7[34]	24	120.13	53.94
Total	167	111.88	53.38

*one missing item, with unidentified pitch contour

The Post-hoc test showed that the duration of Tone5[3] was much shorter when it was followed by Tone6[4], but the duration was not significantly shortened when preceding the other checked tone, Tone5[3]. On the other hand, we could see that Tone1[33], Tone2[313], and Tone7[34] in WF position might lengthen the duration of its preceding tone. To sum up, other than duration, Tone5[3] was not significantly influenced by its following tones in disyllabic words.

We would turn to discuss the results of the other checked tone, Tone6[4] in WI position when it was followed by different tones. As can be seen from Table 4.36, slope and F0 peak alignment of Tone6[4] were influenced by its following tones, $F(6, 161)=2.6937$, $p<.05$. The Post-hoc test showed that the F0 peak alignment of Tone6[4] when followed by Tone1[33] was significantly different from when followed by Tone2[313]. Mean slope of Tone4 followed by different tones was shown in Table 4.37. The temporal point of the peak F0 appeared at about 32.14% of the syllable(SD=34.34), and it appeared at about 7.69% of the syllable (SD=16.82).

Table 4.36: One-way ANOVA: Tone6[4] in WI

Parameters	F(6, 161)	***Sig.***
BP_F0 (Hz)	0.2566	0.956
EP_F0 (Hz)	0.2091	0.974
PEAK_F0 (Hz)	0.2965	0.938
VALLEY_F0 (Hz)	0.1873	0.980
MEAN_F0 (Hz)	0.2686	0.951
DURATION (ms)	0.3065	0.933
SLOPE (Hz/ms)	2.6937	<.05
F0 Peak Alignment (%)	2.3991	<.05
Post-hoc test	**F0 peak alignment**: 4_53 vs. 4_313	<.05

Table 4.37: Tone6[4] in WI—Mean slope when followed by different tones

Parameters	Preceding tone	N	Mean (%)	Std. Deviation
Slope (Hz/ms)	Tone1[33]	24	-0.0854	0.0674
	Tone2[313]	24	-0.0396	0.0810
	Tone3[31]	24	-0.0258	0.0434
	Tone4[53]	24	-0.0589	0.0570
	Tone5[3]	24	-0.0413	0.0577
	Tone6[4]	24	-0.0861	0.0805
	Tone7[34]	24	-0.0708	0.0940
	Total	168	-0.06	0.07
	Preceding tone	N	Mean (%)	Std. Deviation
F0 Peak Alignment (%)	Tone1[33]	24	11.62	23.55
	Tone2[313]	24	32.14	34.34
	Tone3[31]	24	22.64	33.47
	Tone4[53]	24	7.69	16.82
	Tone5[3]	24	18.26	31.08
	Tone6[4]	24	11.09	17.35
	Tone7[34]	24	12.48	25.32
	Total	168	16.56	27.51

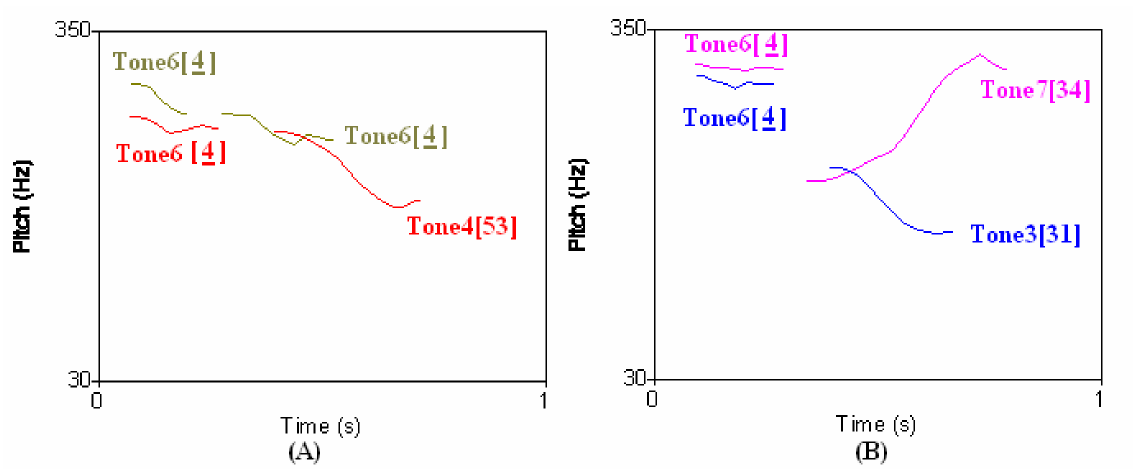


Figure 4.21: Tone6[4] in WI: (A) TA model applied; (B) TA model not applied (By Female_2).

Figure 4.21 showed two sets of pitch contours of Tone6[4] followed by different tones. In Picture (A), the offset F0 of Tone6[4] approximated to the onset F0 of its following tones, which agreed to Xu's (2004) proposition of TA model. On the contrary, the offset F0 of Tone6[4] did not try to approximate to the onset F0 of its following tones when it was followed by Tone3[31] and Tone7[34], which had opposite tone types, [rise] and [fall]. The offset F0 in Picture (B) seemed to stay far away from the target, the onset F0 of the tones in WF.

This interesting results we found in Tone6[4] suggested that not all the tonal variations in Ta-pu Hakka could be applicable to Target Approximation model. The tonal variations we found in Picture (B) in fact demonstrated the fact that some tonal variations in this language did try to show greater contrast between two adjacent tones. With regard to the coarticulation effect, what Picture (A) showed was more like an anticipatory assimilation effect, whereas Picture (B) showed an anticipatory dissimilation effect.

4.5.4 Discussion and Interim Summary

There is a kind of tonal variation found in Tone6[4] in WI and Xu's (2004) Target Approximation model cannot be applicable to this variation. This kind of tonal variation aims to show greater contrast between two adjacent tones. The contrast between two tones can also be found in the sandhi rule of Tone4[53], which is illustrated here in (33) again for easy reference.

(33) Tone4→Tone[55]-OTR／____{Tone3, Tone4, Tone5, Tone6}

This rule also implies that Tone4[53] will remain as [53] when it is followed by Tone1, Tone2, and Tone7, which are all non-falling, non-checked tones. The rule illustrated in (33) indicates that the high falling tone will become a level tone when it is followed by falling tones or checked ones. However, two kinds of mechanisms are involved in this sandhi rule. If we separate the sandhi rule (33) into two subsets, as shown in (34) and (35), we will find that (34) shows dissimilation effect, whereas (35) indicates assimilation effect.

(34) Tone4[53]→Tone[55]-OTR／____{Tone3[31], Tone5[3]}
(35) Tone4[53]→Tone[55]-OTR／____{ Tone4[53], Tone6[4]}

In (34), the offset F0 of Tone4 is raised to reach the high register in order to show contrast with the following tones with mid onset F0. In (35), however, the offset F0 of Tone4 is raised to approximate the high onset F0 of Tone4 and Tone6. The sandhi rule shown in (34) is very close to what we have found in Figure 4.21 (B), whereas Rule (35) shows similar tonal variations shown in Figure 4.21 (A). From this point of view, we can infer that tone sandhi rules must have originated in allophonic variants of tones in different tonal contexts, and then the allophonic variants later came to resemble other tones of the language and were subsequently equated with them (Gussenhoven, 2004, p. 36). We believe that the tonal variations in Tone6[4] are in fact very similar to the sandhi rule (33), only that this variation might be too subtle to form a sandhi rule. In other words, Tone6[4] is a checked tone with falling slope, but the slope is not steep enough to fall down to the lower scale and it is denoted with the T-scale [4]. Thus, it is very unlikely for Tone6[4] to have an allophonic variant such as [44], but the analogy between tonal coarticulation of Tone6[4] and tone sandhi of Tone4[53] does exist.

4.5.5 Conclusion of Adjacent Tone Effects

The findings in the influence of adjacent tones on each other were quite interesting indeed. We found that level and rising tones were affected only by their preceding tones, which showed a carryover assimilation effect. On the other hand, falling and checked tones were affected by their following tones, indicating an anticipatory effect, within which assimilation and dissimilation effects were found. Two of the seven tones in Ta-pu Hakka, Tone4[53] and Tone6[4], were influenced by both their preceding tones and following ones.

4.6 Summary of Tonal Coarticulation

In this Chapter, we have investigated tonal coarticulation in Ta-pu Hakka from different perspectives. In Section 4.3, we first explored the tonal variations in different prosodic positions, which referred to whether a syllable was in word-initial (WI) or in word-final (WF) position in disyllabic words. In Section 4.4, we investigated the tonal coarticulation in compatible, conflicting, and contour compatible contexts. Furthermore, we investigated the tonal coarticulation with regard to how the neighboring tones would influence their adjacent tones.

Several phonological phenomena were found via phonetic realizations. For Tone1[33], Tone7[34], Tone2[313], and Tone6[4], the mean duration was longer when they were in WF position. Thus, a final-lengthening effect was proved to be true via our acoustic data. For Tone3[31] and Tone5[3], the falling slope was steeper when they were in WF position, indicating a final abrupt fall. In regard with the duration of these two tones, it was longer when in WI than in WF, which was just opposite to the final lengthening effect found in the former four tones. Note that Tone5[53], however, was impervious to the prosodic positions.

The most interesting tone was Tone2[313], which had totally different tonal contours when in WI and WF position. Because of the shifting of F0 valley alignment, Tone2[313] was more like a falling tone when in WI position, and it was like a rising tone in WF with positive mean slope. For Tone3[31], the average F0 of all the related parameters was lower in WF position, indicating a phenomenon of declination.

As for the tonal coarticulation in different tonal contexts, we found that the tonal combinations should be classified into compatible, conflicting, and contour compatible context because there were seven tones in Ta-pu Hakka. The results showed that only the slope of Tone3[31] was steeper in a contour compatible context than in a conflicting context. Since no tonal combinations with Tone3[31] had a compatible context, we could only infer from this result that the contour compatible context was similar to the compatible context, in which a falling tone would have a steeper falling slope, which was found in Mandarin Chinese by Xu (1994). However, for Tone7[34], we found that the rising slope was even steeper in a contour compatible context than in a compatible context. Note that no combinations with Tone7[34] in them would have a conflicting context. However, even if we have found that some parameters were influenced by tonal contexts, the general picture of tonal coarticulation in different contexts was still very unclear.

In the investigation of tonal coarticulation influenced by the adjacent tones, we found that Tone1[33], Tone2[313], Tone4[53], Tone6[4] and Tone7[34] were influenced by their preceding tones. The results indicated that this kind of influence was a kind of carryover assimilation. As for anticipatory tonal coarticulation, it was found in Tone3[31], Tone4[53], Tone5[3] and Tone6[4]. The results showed that the anticipatory effect indicated assimilation in the four tones and dissimilation in some items with Tone6[4] in them.

Notes:

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24 This figure is scanned and copied with the permission granted by Xu.

25 Though Tone7[35] was considered as a kind of diminutive form of Tone1[33] (C. Chiang, 1996; M. Chiang, 1998; Tsao & Li, 2005), we still treated Tone7[34] as a phonemic tone in the present study in order to explore its phonetic realizations.

26 Xu (1994) illustrated Tone3_Tone4 as follow: "__╲". Thus, we assumed that Tone3[214] was treated as a low level tone by Xu (p. 2242).

27 The Tone3[31]_Tone1[33] would have a set of pitch contours illustrated as follow: "╲￣".

28 In the investigation of tonal coarticulation via tonal contexts, the T-scale of ST-Tone1 would be denoted its original tonal representations adopted in ***Ta-pu Hakka Dictionary*** (Shü et al., 2005). As for Tone7 in WF, it would be given [34] as its T-scale. However, in the present study, ST-Tone1 and Tone7 are treated as the same tone.

29 Permission granted by Xu.

30 T-scale 4 and 5 were referred to be in the high register, T-scale 3 in the mid register, and Tone 1 and 2 in the low register.

Chapter 5 General Discussion and Conclusion

The present study aims to explore the correlation between phonological representations and phonetic realizations, and to investigate the tonal coarticulation effect in Ta-pu Hakka. As mentioned in Chapter 1, two research questions are addressed in this research. The answers to the two research questions will be discussed in Section 5.1 and 5.2. In Section 5.3, we will discuss the implications and significance of the present study. Some insufficiencies of the present study and suggestions for future study will be addressed in Section 5.4.

5.1 Phonological Representations vs. Phonetic Realizations

In this acoustic study, we have adopted two versions of calculating T-scales in order to verify tonal representations in Ta-pu Hakka by using monosyllabic and disyllabic words as the reading list. Two sets of monosyllabic words, including 14 words and 168 disyllabic words, are chosen. There are six informants recruited in this study, including three males and three females. In calculating T-scales, Fon and Chiang's (1999) and Shi's (1990) versions of formulae are chosen. In this study, when we calculate the T-scales, the average F0 of BP, EP, Peak, and Valley are used in this study instead of the raw data, which was used to calculate the T-scales in Taiwan Mandarin in Fon and Chiang's (1999) study. The average pitch range of the six speakers is 12 semitones, which agrees to Chao's (1968) enlarged pitch range. Note that there are six informants in our study, whereas there was only one speaker in Fon and Chiang's (1999) study. If we calculate the T-scales based on the raw data, we will obtain a very wide pitch range of 26 semitones. As a consequence, the revised T-scales will be confined to Scale [3] or [4], showing a very strange result. As for Fon and Chiang's study in 1999, there was only speaker recruited, so the pitch range was about 6.5 semitones only. Therefore, if there is more than one speaker being recruited in an acoustic study, using average data rather than raw data is more appropriate.

After comparing the exponential correlation between Fon and Chiang's (1999) version and Shi's (1990) version, the result shows that Fon and Chiang's version of verifying the T-scales of Ta-pu Hakka tones is more suitable because the results via their formulae show a non-linear correlation. Besides, the results via their version show better phonetic realizations of the seven tones in Ta-pu Hakka.

In this study, we believe that the citation tones should be based on the tonal representations via monosyllabic words. The revised citation tones are suggested as follows: ***Yin-Ping*** as Tone1[33], ***Supra-Yin-Ping*** as Tone7[34], ***Yang-Ping*** as Tone2[313], ***Shang*** as Tone3[31], ***Chü*** as Tone4[53], ***Yin-Ju*** as Tone5[3] and ***Yang-Ju*** as Tone6[4].

As for sandhi tones, the revised versions via either of the two calculating methods are not appropriate for representing sandhi tones because the revised T-scales in disyllabic words in fact represent the tonal variations that have been influenced by their neighboring tones. Therefore, we suggest that tonal representations in disyllabic words, or even words with multi syllables, should be used as reference only. Even the T-scales of words in WF position should not be regarded as the norms in Ta-pu Hakka. In the present study, we stipulate that the sandhi tones in Ta-pu Hakka should remain their original tonal representations: ST-Tone2 as [33], ST-Tone4 as [55], and ST-Tone as [35]. The original tonal representations of the sandhi tones are also used in investigating tonal coariculation in Chapter 4.

The result of comparing the measured parameters of checked tones indicates that the criteria of distinguishing the two checked tones include not only the average pitch height but also the slope. Tone5[3], the low checked tone, is found to have a steeper falling slope than Tone6[4], the high checked tone, which is the same as Chang's (1995) finding in Miao-li Suu-hsien Hakka. Though the difference is not significant in citation tones, it is significantly different when in disyllabic words.

To sum up, the phonetic realizations of the tonal representations in Ta-pu Hakka suggest that there are two falling tones, one in the higher register, and the other in the lower register, one level tone, one rising tone, one concave tone, and two checked tones. If sandhi tones are included, and if the concave tone is regarded as the phonetic realizations of the underlying low level tone, the tonal system in Ta-pu Hakka is in fact quite complete, three level tones (in [high], [mid], and [low] register), two falling tones (in [upper] and [lower] register), and two checked tones (in [high] and [mid] register).

According to the results of phonetic realizations of the revised tonal representations, we propose that rising tones are likely to have a phonetic fall in a syllable. The phonetic realizations of a low level tone indicate that it is actually a concave tone, with initial fall and final rise. The phonetic realizations of the tones in this language also show that if there are more tones in a language, the pitch range will be enlarged and the tones in this language will be more equally distributed along the five-scaled system.

5.2 Tonal Coarticulation

Tonal coarticulation has been studies from different perspectives. Prosodic effect and context effect are investigated and discussed most often. Xu's Target Approximation model was not proposed until the past decade (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001). In this study, tonal variations in disyllabic words are explored with regard to the influence of prosodic positions, the tonal contexts, and the adjacent tones on the target tone.

The results of comparing means of the measured parameters of a target tone in different prosodic positions show final lengthening and declination. All the seven citation tones are influenced in some parameters in different positions except for Tone4[53], which is impervious to prosodic positions. We assume that if Tone[4] would be influenced by prosodic positions, it would have already turned a sandhi tone [55]. The results of prosodic position effect also suggest that Tone3[31] and Tone5[3] show similar tonal variations, indicating that the two tones can be treated as a group. For non-falling tones, Tone1[33], Tone2[313] and Tone7[34], the results show final lengthening effect, and the three tones can be treated as a group. Again, the grouping of tones in Ta-pu Hakka can be found in tonal coarticulation.

As for tonal contextual effect on tonal coarticulation in Ta-pu Hakka, the results indicate that dividing tonal combinations into the three contexts, compatible, conflicting and contour compatible, is not able to clarify the tonal variations in this language. The unequal numbers in the three contexts also have some impact on the validity of statistical results.

As for the results of adjacent tone effect, the grouping of tones in this language appears again. According to the direction of tonal coarticulation, three groups can be classified as a consequence. Tone1[33], Tone2[313], and Tone7[34] are influenced only by their preceding tones, and the results indicate a carryover assimilation effect. For Tone3[31], Tone5[3], they are influenced by their following tones, and the results show a kind of anticipatory assimilation effect. For Tone4[53] and Tone6[4], they are influenced not only by their preceding tones but also by their following tones. The results show that both anticipatory and carryover assimilation are found in both tones. In the above two groups, Xu's TA model (Chen & Xu, 2006; Xu, 1997, 1999, 2004; Xu & Wang, 2001) helps explain the positive correlation between the adjacent pitch targets. On the other hand, Tone6[4] shows an anticipatory dissimilation effect when it is followed by Tone3[31] and Tone7[34]. The results also show that TA model is not able to explain the phenomenon we found in Tone6[4], which is very close to two of the Tone4[53] sandhi rules as discussed in Section 4.5.3.4. This anticipatory dissimilation effect shows that the adjacent pitch targets are trying to stay far away from each other in order to show greater contrast.

This interesting opposite phenomenon can also be found in the tone sandhi rules in Ta-pu Hakka. Most of the tone sandhi rules in disyllabic words of Ta-pu Hakka show dissimilation effect, such as ***Yin-Ping Tone Sandhi***, ***Yang-Ping Tone Sandhi***, and ***Chü Tone Sandhi*** when Tone4[53] is followed by Tone3[31] or Tone5[3].

Though Xu's Target Approximation model does shed a light in explaining most of the tonal coarticulation phenomena found in Ta-pu Hakka, the result of the anticipatory dissimilation effect suggests that this model is not applicable to all the tonal variations in this language.

To sum up, the direction of tonal coarticulation in Ta-pu Hakka is bidirectional. Anticipatory tonal coarticulation exhibits both dissimilation and assimilation phenomena. As for carryover tonal coarticulation, it demonstrates assimilation effect on adjacent tones. The tonal coarticulation in Ta-pu Hakka not only tries to show harmony and agreement between adjacent tones, but also tries to enlarge the contrast between them in some of the tonal combinations.

5.3 Contributions of This Study

Empirically, we believe that this study is the first acoustic study of tones in Ta-pu Hakka. As a fundamental research in the correlation between phonetics and phonology, this study contributes to exploring the correlation between phonological representations of tones and their phonetic realizations and to a more in-depth study of tonal coarticulation in Ta-pu Hakka. Furthermore, our revised tonal representations can not only show the phonetic realizations of tones in this language but also group those tones in pairs.

As for the methodology, we modify and reconstruct Fon and Chiang's (1999) formulae according to the average pitch range obtained from our six informants. We also propose that Fon and Chiang's (1990) formulae are more suitable for verifying T-scales in Ta-pu Hakka because these formulae indicate a non-linear correlation. We adjust and modify these formulae because we believe that a five-scaled system is needed to represent Ta-pu Hakka tones because there are seven citation tones and three sandhi tones in this language. The results in Chapter 3 also suggest that a five-scaled system is enough for the ten tones to differentiate one from another.

Furthermore, by adopting two versions of calculating T-scales of tonal representations, we hope to shed a light in the study of tones with regard to exploring the correlation between phonological representations and phonetic realizations. The results of our revised version of tonal representations in Ta-pu Hakka provide acoustic evidence for us to answer the question as to what the phonetic realizations of tonal representations really are.

In theoretical concern, we adopt Xu's (1994) definition of compatible and conflicting contexts with an additional context found in Ta-pu Hakka, which is a contour compatible context. Under the three kinds of contexts, the results show that a contour compatible context is very similar to a compatible context. As for Xu's TA model (Xu & Wang, 2004; Xu, 2004; Chen & Xu, 2006), it surely can explain most of the assimilated tonal coarticulation phenomena, but it might be insufficient with respect to the dissimilated tonal coarticulation in Ta-pu Hakka.

5.4 Limitations of the Study and Suggestions for Future Study

The limitation of the study lies in the scarcity of monosyllabic-word stimuli. We thus suggest the increasing of the sample size of monosyllabic words to involve different types of syllabic structures with different initials. In this way, the test items will be enough to verify the tonal representations of each individual.

As for investigating tonal coarticulation, the F0 of a syllable via normalized time have been widely used, but there has been suggestion that "real" time step should be taken into consideration (Wong, 2006). In the present study, by using the raw data from real time step, the real and authentic pitch contours are able to be presented. For future research, we suggest that the F0 value in normalized duration be used, so the data can be put into the TA model and the pitch target can be calculated.

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Appendix I

Word List of Monosyllabic Words: Tonal Representations in RTR

RTR	Chinese Character	IPA	Glossary
Tone1	牽	[kʰjɛn]	to lead someone by holding their hands
[33]	馬	[mɑ]	a horse
Tone2	權	[kʰjɛn]	power
[313]	痲	[mɑ]	numb
Tone3	譴	[kʰjɛn]	to be angry
[31]	麼	[mɑ]	what
Tone4	勸	[kʰjɛn]	to persuade
[53]	罵	[mɑ]	to scold
Tone7	圈	[kʰjɛn]	a circle
[34]	馬（卵）	[mɑ]	as in [ma]35_[lɔn]31 “a horse’s testicle”
Tone5	缺	[kʰjɛt]	to lack
[3]	襪	[mɑt]	socks
Tone6	傑	[kʰjɛt]	be outstanding
[4]	末	[mɑt]	the end of something

Appendix II

Word List of Disyllabic Words: Tonal Representations in RTR

(T1: [33], T2[313], T3[31], T4[53], T5[3], T6[4], T7[34], ST-T1: [35], ST-T2: [33], ST-T4: [55])

Tone	Chinese Characters	IPA	Glossary
T1_T1	開花	[kʰɔɪ]_[fɑ]	to bloom
	開山	[kʰɔɪ]_[sɑn]	to bring wasteland in the mountains under cultivation
	開通	[kʰɔɪ]_[tʰɔŋ]	open-minded
	開春	[kʰɔɪ]_[tsʰun]	beginning of spring
T1_T2 (ST-T1_T2)	開頭	[kʰɔɪ]_[tʰɛʊ]	to begin; from the start
	開田	[kʰɔɪ]_[tʰjɛn]	to bring wasteland under cultivation; to open ground
	標頭(商標)	[pʰjaʊ]_[tʰɛʊ]	a trademark; a brand label; a logo
	開錢	[kʰɔɪ]_[tɕʰjɛn]	to spend money
T1_T3 (ST-T1_T3)	開火	[kʰɔɪ]_[fo]	to fire
	開採	[kʰɔɪ]_[tsʰaɪ]	to mine; to exploit
	開墾	[kʰɔɪ]_[kʰun]	to bring wasteland under cultivation
	開口	[kʰɔɪ]_[kʰjɛʊ]	to start talking
T1_T4	開竅	[kʰɔɪ]_[kʰjaʊ]	to enlighten sb.; to understand
	開票	[kʰɔɪ]_[pʰjaʊ]	(of an election) counting and announcing the ballots
	開砲	[kʰɔɪ]_[pʰaʊ]	to open fire with artillery; to fire
	澎湃(豐盛)	[pʰɔŋ]_[pʰaɪ]	sumptuous (feast)
T1_T5 (ST-T1_T5)	開發	[kʰɔɪ]_[fɑt]	to exploit; to open up and develop
	開缺	[kʰɔɪ]_[kʰjɛt]	to offer a vacancy
	開桌	[kʰɔɪ]_[tsɔk]	to start eating (at a feast)
	空缺	[kʰɔŋ]_[kʰjɛt]	a vacancy
T1_T6	開學	[kʰɔɪ]_[hɔk]	School opens.
	科學	[kʰo]_[hɔk]	science
	開鑿	[kʰɔɪ]_[tsʰɔk]	to dig or to excavate
	空白	[kʰɔŋ]_[pʰɑk]	blank
T1_T7	貪杯	[tʰɑm]_[pʊɪ]	to indulge in drinking
	豬胚	[tʃu]_[pʰɔɪ]	a piggy
	拖箱(抽屜)	[tʰo]_[sjɔŋ]	a drawer
	工蜂	[kɔŋ]_[pʰɔŋ]	a worker bee

T2_T1	茶山	[tsʰɑ]_[sɑn]	a hill that grows tea trees
	茶花	[tsʰɑ]_[fɑ]	a camellia
	茶青	[tsʰɑ]_[tɕʰjɑŋ]	fresh tea leaf
	盤車(轉車)	[pʰɑn]_[tʃʰɑ]	to transfer car
T2_T2 (ST-T2_T2)	焤茶(煮茶)	[pʰu]_[tsʰɑ]	to boil tea down
	枇杷	[pʰi]_[pʰɑ]	loquat
	葡萄	[pʰu]_[tʰo]	grape
	茶盤	[tsʰɑ]_[pʰɑn]	a tea tray
T2_T3	茶水	[tsʰɑ]_[ʃʊɪ]	tea
	歕火(吹火)	[pʰun]_[fo]	to blow the fire and make it burn more quickly
	搽粉	[tsʰɑ]_[fun]	to powder
	貧苦	[pʰɪn]_[kʰu]	impoverished
T2_T4	排氣	[pʰaɪ]_[kʰi]	to exhaust
	脾氣	[pʰi]_[kʰi]	temper
	才氣	[tsʰaɪ]_[kʰi]	talent and gift
	攀樹(爬樹)	[pʰɑn]_[ʃu]	to climb a tree
T2_ T5	肥缺	[pʰʊɪ]_[kʰjɛt]	a fat job or office
	茶骨	[tsʰɑ]_[kʊt]	tea leaf stalk
	菩薩	[pʰu]_[sɑt]	Buddha
	頭七	[tʰɛu]_[tɕʰɪt]	a ceremony to express condolence over sb's death on the seventh day
T2_T6	跟緊	[tʰɛn]_[hɛt]	follow sb closely
	綯核 (綁住)	[tʰo]_[hɛt]	to tie together
	提拔	[tʰi]_[pɑt]	to promote sb. to a higher position
	稠直	[tʰjaʊ]_[tɕʰɪt]	be upright
T2_T7	騎車	[kʰi]_[tʃʰɑ]	to ride a motorcycle or a bike
	投牲(家禽)	[tʰɛʊ]_[sɑŋ]	livestock
	頭胎	[tʰɛʊ]_[tʰɔɪ]	first-born child
	屯溝 (填水溝)	[tʰun]_[kjɛʊ]	to fill and level up a ditch

T3_T1	採風	[tsʰaɪ]_[fɔŋ]	to ventilate; adequately ventilated
	採花	[tsʰaɪ]_[fɑ]	to pick flowers
	採買	[tsʰaɪ]_[maɪ]	to buy; to shop
	討親(娶親)	[tʰo]_[tɕʰɪn]	to marry (a woman)
T3_T2	彩陶	[tsʰaɪ]_[tʰo]	faience; painted pottery
	採茶	[tsʰaɪ]_[tsʰɑ]	to pick tea
	彩頭	[tsʰaɪ]_[tʰɛʊ]	an auspice
	討錢	[tʰo]_[tɕʰjɛn]	to ask for or beg for money
T3_T3	土產	[tʰu]_[sɑn]	local specialty or products
	採訪	[tsʰaɪ]_[fɔŋ]	(of a journalist) to cover (some event); to interview
	聘請	[pʰɪn]_[tɕʰjɑŋ]	to employ or to engage sb.
	癉癉(疲憊)	[tʰjɑm]_[tʰjɑm]	tired and weary
T3_T4	普遍	[pʰu]_[pʰjɛn]	common and usual
	聘便(約定好)	[pʰɪn]_[pʰjɛn]	to agree on sth in advance
	普渡	[pʰu]_[tʰu]	to arrange a feast for the death (especially in mid July of the lunar calendar)
	土話	[tʰu]_[fɑ]	a patois; a local dialect
T3_ T5	孔撇(倒掉)	[kʰɔŋ]_[pʰɛt]	to empty a pot or a plate
	彩色	[tsʰaɪ]_[sɛt]	color
	探測	[tʰɑm]_[tsʰɛt]	to probe or to explore
	體質	[tʰi]_[tɕɪt]	a physique; the health condition of one's body
T3_ T6	揪核(揪著)	[kʰju]_[hɛt]	to tug (at sth)
	漂白	[pʰjaʊ]_[pʰɑk]	to bleach
	討食(乞討)	[tʰo]_[ʃɪt]	to ask for food or to beg for food
	口舌	[kʰjɛʊ]_[ʃɛt]	mouth and tongue
T3_T7	土雞	[tʰu]_[kje]	a chicken raised in the field
	紙遮(紙傘)	[tɕi]_[tʃɑ]	a paper umbrella
	駛車(開車)	[sɨ]_[tʃʰɑ]	to drive (a car)
	頸根(頸子)	[kjɑŋ]_[kɪn]	neck

T4_T1	泡湯	[pʰaʊ]_ [tʰɔŋ]	to take a hot-spring bath
	大風	[tʰaɪ]_[fɔŋ]	big and strong wind
	背風	[pʰɔɪ]_[fɔŋ]	leeward
	代書	[tʰɔɪ]_[ʃu]	an occupation, the one who write legal document for others
T4_T2	派頭	[pʰaɪ]_[tʰɛu]	usually haughty style or manner
	剖柴	[pʰo]_[tɕʰjaʊ]	to chop wood
	噴頭	[pʰun]_[tʰɛu]	nozzle
	病猴	[pʰjɑŋ]_[hɛu]	those who get sick very easily
T4_T3 (ST-T4_T3)	大水	[tʰaɪ]_[ʃʊɪ]	flood
	焙火(烤火)	[pʰɔɪ]_[fo]	to bask by the fire
	便所(廁所)	[pʰjɛn]_[so]	a toilet
	背手 (不順手)	[pʰɔɪ]_[ʃju]	unable to do something smoothly
T4_T4 (ST-T4_T4)	泡菜	[pʰaʊ]_[tsʰɔɪ]	Chinese pickled vegetables
	大菜(芥菜)	[tʰaɪ]_[tsʰɔɪ]	leaf mustard
	便菜	[pʰjɛn]_[tsʰɔɪ]	potluck
	在在 (四平八穩)	[tsʰaɪ]_[tsʰaɪ]	firm and steady
T4_ T5 (ST-T4_ T5)	敗撇(敗壞)	[pʰaɪ]_[pʰɛt]	ruined and stale
	辦法	[pʰɑn]_[fɑt]	method
	呸撇(吐掉)	[pʰʊɪ]_[pʰɛt]	to spew out sth.
	(中心)空空的	[pʰɑŋ]_[pʰɛt]	to describe food or fruit which has a hollow inner part
T4_ T6 (ST-T4_ T6)	大學	[tʰaɪ]_[hɔk]	a university
	大局	[tʰaɪ]_[kʰjʊt]	overall situation
	大族	[tʰaɪ]_[tsʰʊk]	a big clan
	大鑊	[tʰaɪ]_[vɔk]	a big pot
T4_T7	大姑	[tʰaɪ]_[ku]	father's big sister
	替身 (替死鬼)	[tʰe]_[ɕɪn]	a scapegoat
	噭包 (愛哭的男生)	[kjɛʊ]_[paʊ]	boys who cries a lot
	幼沙(細沙)	[ʒju]_[sɑ]	tiny sand

T5 _T1	鐵窗	[t^{h}jɛt]_[ts^{h}ɔŋ]	a window with iron grating
	墊被	[t^{h}jɑp]_[p^{h}i]	a quilt used as a mat
	鐵青	[t^{h}jɛt]_[tɕ^{h}jɑŋ]	be livid
	忒多	[t^{h}ɛt]_[to]	too much or too many
T5 _T2	鐵皮	[t^{h}jɛt]_[p^{h}i]	iron sheet
	鐵床	[t^{h}jɛt]_[ts^{h}ɔŋ]	a bed made of iron
	忒長(太長)	[t^{h}ɛt]_[tʃ^{h}ɔŋ]	too long
	鐵鎚	[t^{h}jɛt]_[tɕ^{h}ʊɪ]	a hammer
T5 _T3	伐草(砍草)	[p^{h}ɑt]_[ts^{h}o]	to weed by using a scythe
	鐵桶	[t^{h}jɛt]_[t^{h}ɔŋ]	a pail or a bucket made of iron or any metal
	脫水	[t^{h}ɔt]_[ʃʊɪ]	to dehydrate
	割草	[kɔt]_[ts^{h}o]	to weed by using a sickle
T5 _T4	曝曬	[p^{h}ʊk]_[saɪ]	to expose to the sun
	拆散	[ts^{h}ɑk]_ [sɑn]	to break (a marriage, family, etc.)
	覆菜	[p^{h}ʊk]_[ts^{h}ɔɪ]	pickled leaf mustard
	忒太(太大)	[t^{h}ɛt]_[t^{h}aɪ]	too big
T5 _ T5	脫殼	[t^{h}ɔt]_[k^{h}ɔk]	to cast the shell
	脫色	[t^{h}ɔt]_[sɛt]	to decolor, to fade
	脫撇(脫掉)	[t^{h}ɔt]_[p^{h}ɛt]	to take off
	鐵筆	[t^{h}jɛt]_[pɪt]	cutting tools; stencil pens
T5_ T6	覆核(倒扣放著)	[p^{h}ʊk]_[hɛt]	to place upside down
	托核(托著)	[t^{h}ɔk]_[hɛt]	to hold in the palm of the hand
	拆藥(抓藥)	[ts^{h}ɑk]_[ʒɔk]	to buy Chinese herbal medicine according to a doctor's prescription
	合藥(配藥)	[kɑp]_[ʒɔk]	to dispense (medications)
T5 _T7	鐵馬	[t^{h}jɛt]_[mɑ]	a bicycle
	漆車	[tɕ^{h}ɪt]_[tʃ^{h}ɑ]	to paint a car
	摘柿	[tsɑk]_[k^{h}i]	to pick persimmons
	竹修	[tʃʊk]_[ɕju]	bamboo branches tied together used to scold and hit sb. (especially children)

T6 _T1	讀書	[t^{h}ʊk]_[ʃu]	to read books or to study
	柵間(隔間)	[ts^{h}ɑk]_[kjɛn]	partition of a house or an apartment
	毒心	[t^{h}ʊk]_[sim]	an evil heart
	讀音	[t^{h}ʊk]_[ʒɪm]	pronunciation
T6 _T2	毒蛇	[t^{h}ʊk]_[ʃɑ]	a poisonous snake
	白頭	[p^{h}ɑk]_[tɛʊ]	white hair all over the head
	白蛇	[p^{h}ɑk]_[ʃɑ]	a white snake
	別儕(別人)	[p^{h}ɛt]_[sɑ]	other people
T6 _T3	白果	[p^{h}ɑk]_[ko]	a ginkgo nut
	白手	[p^{h}ɑk]_[sju]	by one's own effort
	白癬	[p^{h}ɑk]_[sjɛn]	tinea
	薄紙	[p^{h}ɔk]_[tɕi]	thin paper
T6 _T4	擇菜(揀菜)	[t^{h}ʊk]_[ts^{h}ɔɪ]	to choose and pick vegetables
	白菜	[p^{h}ɑk]_[ts^{h}ɔɪ]	Chinese cabbage
	白飯	[p^{h}ɑk]_[[p^{h}ɔn]	rice
	白費	[p^{h}ɑk]_[fʊɪ]	in vain
T6 _ T5	奪色(染色)	[t^{h}ɔt]_[sɛt]	to dye from something else
	白髮	[p^{h}ɑk]_[fɑt]	white hair
	白鐵	[p^{h}ɑk]_[t^{h}jɛt]	galvanized iron
	白色	[p^{h}ɑk]_[sɛt]	white (color)
T6 _ T6	白鶴(白鷺)	[p^{h}ɑk]_[k^{h}ɔk]	a white crane
	伏核(趴著)	[p^{h}ʊk]_[hɛt]	to lie prone
	獨獨(單單)	[t^{h}ʊk]_ [t^{h}ʊk]	solely
	毒藥	[t^{h}ʊk]_[ʒɔk]	poison
T6 _T7	白哥(溪哥)	[p^{h}ɑk]_[ko]	a kind of river fish
	著花(中彩)	[tʃ^{h}ɔk]_[fɑ]	to win the lottery
	熟番	[ʃʊk]_[fɑn]	an aboriginal
	學生	[hɔk]_[sɑŋ]	a student