Initial strengthening of lexical tones in Taiwanese Min

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Abstract

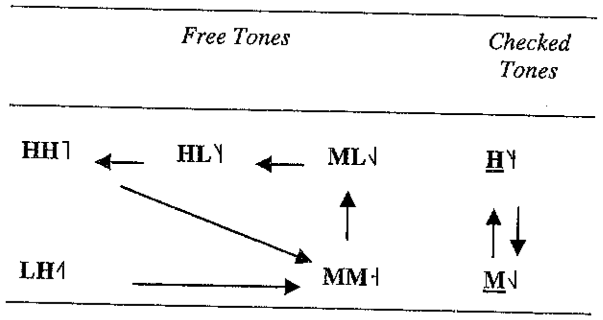
Recently, it has been shown that the strength of prosodic boundaries is reflected in the articulation of post-boundary segments ('initial strengthening'). This study extends the scope of articulatory prosody to a suprasegmental level by investigating the effect on the realization of lexical tones by preceding IP, tone group, word and syllable boundaries. Four falling tones were combined with four types of boundary in broad focus SVO sentences, and produced by three male and two female native speakers of Taiwanese. Maximal F_0 (F_0max), minimal F_0 (F_0min), and F_0 range of post-boundary syllables were analyzed. The results indicate that (1) domain-initial F_0 range is influenced by boundary type; (2) the extent of F_0 range expansion correlates positively with the strength of the preceding boundary: TNGP > WRD > SYL; (3) an expansion of the F_0 range is achieved by either raising the F_0max or by lowering the F_0min; and (4) tone group boundary, not a level of a prosodic hierarchy, affects the surface F_0 by lowering the minimum F_0 values.

1. Introduction

1.1. Taiwanese lexical tones

Taiwanese has seven lexical tones including two checked tones. The five free tones are high level (HH), rising (LH), high falling (HL), mid falling (ML), and mid level (MM) tones, and the two checked tones are high falling (H̲) and mid falling (M̲) tones. The two checked tones occur on V(C) rhymes where the C is a voiceless stop, while the five free tones occur on V(C) rhymes where the C is a nasal consonant. Each tone has two (allophonic) variants, one occurring at a tone group boundary, and the other, a 'sandhi tone', occurring internally within the tone group (Cheng 1968; Cheng 1973; Ting 1985; Zhang 1989; Peng 1997). Though opinions vary, most studies describe the Taiwanese sandhi tone as resulting from a chain rule. Specifically, syllables with high and rising juncture tones surface as a mid level tone in a non-juncture position (HH, LH → MM); syllables with a mid level tone surface as a mid falling tone in a non-juncture position (MM → ML); syllables with a mid falling juncture tone surface as a high falling tone in a non-juncture position (ML → HL); syllables with a high falling juncture tone surface as a high level tone in a non-juncture position (HL → HH). Checked syllables with a high falling checked juncture tone surface with a low falling checked sandhi tone (H → M), while checked syllables with a low falling checked juncture tone surface with a high falling checked sandhi tone (M → H). This is shown in Table 1 (Cheng 1968; Cheng 1973; Chen 1987; Cheng and Cheng 1977; Hsieh 1970; Zhang 1989).

Table 1. Taiwanese tonal sandhi rules



In short, the surface tonal values for Taiwanese syllables are determined by the syllable's position within the domain of the tone group. To illustrate, the phrases in (1) are produced with two morphemes, /lɔ˥˩ / 'stew' and /tsai˧˩ / 'vegetable'. In the first phrase, [lɔ˥] 'stew' is produced in phrase initial position with a sandhi tone while [tsʰai ˧˩] 'vegetable' is produced before the boundary's edge with a juncture tone. The reverse occurs in the second phrase, where [lɔ˥˩] 'stew' is produced with a juncture tone and [tsʰai ˥˩] 'vegetable' is produced with a sandhi tone.

(1) VP: / lɔ˥˩ be ˧ tsʰai ˧˩ / [lɔ˥ be ˧˩ tsʰai˧˩]tone group 'to stew cabbage'
NP: / be ˧ tsʰai ˧˩ lɔ˥˩ / [be˧˩ tsʰai˥˩ lɔ˥˩]tone group 'cabbage stew'

The status of the tone group in the prosodic hierarchy in Taiwanese is a much debated issue. While Hsiao (1991) has claimed that the tone group is potentially part of the prosodic hierarchy, there are a number of reasons for not including the tone group in the hierarchy. First, a tone group is not systematically marked by intonation features. That is, speakers produce a juncture tone before the boundary regardless of the intonation. Second, the domain of the tone

group generally coincides with syntactic grouping. In cases where it does not, it has been proposed that the delimitation of a tone group is prosodically determined, though the prosodic criteria for determining the tone group boundary have not been made explicit (Chen 1987; Hsiao 1991; Lin 1994; Chen 2000). Third, the tone group violates the Strict Layer Hypothesis (Selkirk 1984), which assumes that a lower level prosodic domain is exhaustively contained within a higher level prosodic domain. For example, syllables are nested within words, which in turn are nested inside an IP. However, tone group boundaries sometimes coincide with higher prosodic levels, such as an IP, while at other times they only coincide with lower constituents, such as the word, where there is clearly no IP-boundary. In the following examples, the tone group coincides with the IP, as in (2), but with free morpheme within a compound word, as in (3). The word / tʰai ˧˩ tsu ˥˩ / 'prince' in (3) is a registered brand name. The entire compound noun contains two tone groups, with a tone group boundary between the free morphemes / tʰai ˧˩ tsu˥˩ / 'prince' and / kĩũ ˥ bo˥˩ / 'ginger'. This tone group boundary does not coincide with the higher level prosodic boundary.

(2) / gua˥˩ tʰak ˥ pũã ˧˩ tiam ˥˩ tsiŋ ˥ ku ˥˩ tsʰeʔ ˧˩ /
[gua ˥ tʰak ˧˩ pũã ˥˩ tiam ˥ tsiŋ ˧ ku ˥ tsʰeʔ ˧˩]tone group
[np gua ˥] [vp[vtʰak ˧˩] [np[adjp pũã ˥˩ tiam tsiŋ ˧ ku ˥][n tsʰeʔ ˧˩]]]
I study half hour long book
'I studied for half an hour.'

(3) / tʰai ˧˩ tsu ˥˩ kĩũ ˥ bo ˥˩ aʔ ˧˩ /
[tʰai ˥˩ tsu ˥˩]tone group [kĩũ ˧ bo ˥ aʔ ˧˩]tone group
[np tʰai ˥˩ tsu ˥˩ kĩũ ˧ bo ˥ aʔ ˧˩]
Prince ginger duck
'Prince® ginger duck'

In a study comparing VOT of Taiwanese stops in tone group initial and medial positions, Hsu and Jun (1996) found that VOTs were greater in the initial position of a tone group than in the final position, and suggested that the VOT was indicative of initial strengthening at the tone group. However, recognizing that this view implied a violation of the Strict Layer Hypothesis, they proposed that both prosodic and non-prosodic boundaries can trigger initial strengthening. In fact, domain-final lengthening – another indicator of boundary strength – has been found to be influenced by discourse factors in Standard Chinese (Fon and Johnson 2004). It would appear therefore, that boundary strength can be observed around both prosodic and non-prosodic boundaries, and that the Taiwanese tone group needs not be part of the prosodic hierarchy if it were to influence initial strengthening. By providing lexical tonal data, this study intends to expand the horizon of articulatory prosody from the level of segmental articulation to that of suprasegmental articulation.

1.2. Prominence and boundary strength

Although most research on the effect of prosodic structure on articulation has addressed segments, Byrd (2003) pointed out the need to include tone and intonation. Among the prosodic factors influencing articulation, prominence and boundary strength have received the most attention. Prominence strength has been shown to affect the course of lip, tongue, and jaw movements, which display more canonical trajectories in accented or focused positions (de Jong 1995; Krakow 1999; Fougeron and Keating 1997; Cho 2002, 2004, 2005). Studies of the effect of focus (prominence) on lexical tone have found that local pitch span was expanded during syllables with narrow focus and reduced for post-focus syllables in Beijing Mandarin (Jin 1995; Xu 1999). Unlike what appears to happen in Beijing Mandarin, both F_0 range expansion and duration elongation were observed on narrow focused syllables in Taiwan Mandarin (Hsiong 2002; Huang 2004). Moreover, narrow focused syllables in Taiwanese raised F_0 and lengthened duration (Pan 2001).

Boundary strength has been investigated from two viewpoints. First, domain-initial strengthening has been compared with domain-medial weakening (Fougeron and Keating 1997; Byrd and Saltzman 1998; Fougeron 2001; Cho 2002, 2004, 2005). Byrd and Saltzman (2003) used the pi gesture to model the local shrinking and stretching of articulatory trajectories around prosodic boundaries. They proposed the existence of a central clock controlling the speed of articulatory movements as they approach and recede from boundaries. As the central clock speeds up, the articulatory trajectories shrink, whereas when the clock slows down, the articulatory trajectories stretch or expand. The speed of the central clock decreases before an approaching boundary.

In addition to articulatory strengthening and weakening through prosodic domains, the second viewpoint, concerns the variation of articulation due to the rank of the boundary at a given location, has been observed that articulatory movements gradually weaken as the adjacent boundary varies from a high to a low rank in the prosodic hierarchy. For example, Cho (2002) found that for word final and initial /m/, the open phase of labial movements and total duration of labial movements is longer before an IP boundary than before a word boundary. Tabain (2003a, 2003b), in an acoustical and EMA study, investigated lingual and jaw movements for French /aC/ sequence across utterance, IP, accentual phrase and word boundaries. It was found that a stronger prosodic boundary induced much lower tongue, body and jaw positions than a weaker boundary. Acoustically, F1 for /a/ was higher before a stronger boundary than before a weak one.

The study reported here explored the effect of boundary type on the realization of lexical tones after IP, word, syllable and tone group boundaries in different as well as identical positions in the sentence. In the first experiment, the target syllables were produced after word, syllable and tone group boundaries in serial positions; while, in the second experiment, the target syllables were aligned after IP, word, syllable and tone group boundaries in the same position. Among these boundaries, the status of a tone group boundary was of special interest, as it was not traditionally classified as a prosodic boundary.

2. Methods

2.1. Speakers

Three male native Taiwanese speakers, CYS, LWS and LYK, participated in Experiment 1, which had the boundaries in serial positions. For Experiment 2, which involved a same-position boundary, one male speaker, YZJ, and, two female speakers, HHP and HSR participated. They were all trilingual speakers of Taiwanese, Mandarin and English. The speakers were either faculty members or students at National Chiao Tung University at the time of the recordings.

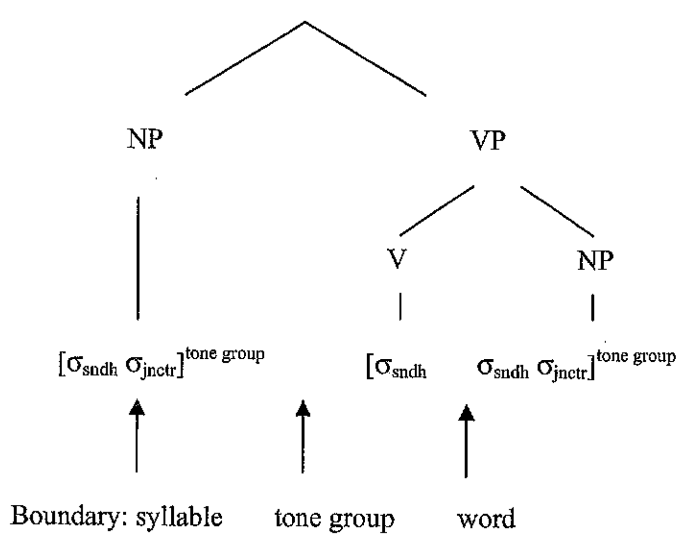
2.2. Corpus

2.2.1. Experiment 1

The corpus for the boundaries in serial position contained SVO sentences with five syllables (see Table 2). The first and second syllables were surnames and formed the subject; the third and fourth syllables formed a transitive verb; the fourth and fifth syllables formed the object. The tonal value of the first syllable was held constant as a mid level tone, while the tonal values of the second, third and fourth syllables varied between six different lexical tones: high level (HH), high falling (HL), mid falling (ML), mid level (MM), high falling checked (H̲), and low falling checked (M̲) tones. The fifth syllable was held constant as a HL tone, the only exception here being the morpheme [ləŋ˧], produced with a mid level (MM) tone (Table 2).

The first and second syllables (the surname) formed one tone group, while the third, fourth, and fifth syllables (the predicate) formed another tone group. Thus, syllables one, three, and four had sandhi tones, while syllables two and five had juncture tones, as shown in (4).

(4)



In the experimental sentences, the syllable, word and tone group boundary of interest appeared consecutively in this order. That is, the syllable boundary (SYL) was after the second syllable; the word boundary (WRD) was after the third syllable; and the tone group boundary (TNGP) was after the fourth syllable (see (4)). The first syllable in each of these utterances always had the a MM tone. This tone was not investigated even though it was produced at the left-most edge of the IP boundary.

By commuting six tone types in the second, third and fourth syllables, 216 sentences were formed. Not all the sentences were semantically comprehensible; however, speakers had no problem producing them. Each sentence was designed to carry four different focus conditions, i.e. broad focus, narrow focus on subject, verb or object. Each of these expressions was repeated three times. The order of the sentences was randomized. A total of 2592 utterances (6 names × 6 verbs × 6 objects × 4 focus conditions × 3 repetitions) were collected per speaker.

Table 2. Corpus for Experiment 1 with boundaries in serial positions. Tones are in underlying form within / / and surface form within [ ]. The "˜ " over the vowel means nasalisation.

Subject	Verb	Object
[˧ ˥] /a ˥ me ˥/	[˥] /lam ˥˧/ 'hug'	[˥ ˥˧] /liu ˥˧ a ˥˧/ 'button'
[˧ ˥˧] / a ˥ mã ˥˧ /	[˥˧] / liam ˧˩ / 'pinch'	[˥˧ ˧] / a ˧˩ ˥ əŋ ˧ /'duck egg'
[˧ ˧˩] / a ˥ lun ˧˩ /	[˧˩] / mã ˧ / 'scold'	[˧˩ ˥˧] / lua ˧ a˥˧ / 'comb'
[˧ ˧] / a ˥ liaŋ ˧ /	[˧] / law ˨˦ / 'save'	[˧ ˥˧] / ŋ̃iũ ˨˦ a˥˧ / 'silkworm'
[˧ ˥˧̲] / a ˥ lat ˥˧̲ /	[˥˧̲] / lak ˧˩̲ / 'lose'	[˥˧̲ ˥˧] / lok ˧˩̲ a ˥˧/ 'bag'
[˧ ˧˩̲] / a ˥ lok ˧˩̲ /	[˧˩̲] / lap ˥˧̲ / 'pay'	[˧˩̲ ˥˧] / liap ˥˧̲ a ˥˧ / 'blister'

The data studied here was part of the large data set designed to investigate the effects of focus condition. Only the broad focus sentences, elicited as answers to the precursor question 'What happened?' were examined in the present investigation. Moreover, to ensure easy identification of the F_0 peaks and valleys, only the falling tones followed by HL or MM tonal targets were investigated. Thus four tonal sequences were studied, i.e. a target high falling tones followed by mid-level tones (HL+MM), a target low falling tones followed by a high falling tone (ML+HL), a target high falling checked tone followed by a high falling tone (H̲+HL), and a target low falling checked tones followed by a high falling tone (M̲+HL) across syllable, tone group and word boundaries. For each speaker, 420 sentences remained after this selection process.

The effect of hierarchical rank was examined in different linear positions, such that the syllable boundary was always studied after the second syllable, the tone-group boundary after the third syllable and the word boundary after the fourth syllable. Since the effects of boundary and linear position are conflated, care must be taken to take account of the effect of declination when drawing conclusions about the effects of boundary type in Experiment 1. For this reason, a second restricted data set with boundaries at the same position, after the second syllables, was analyzed in Experiment 2 to investigate the effect of boundary rank independently of position.

2.2.2. *Experiment 2*

For the corpus with boundaries in the same position, sentences with five syllables were used. Four boundaries, i.e. intonation phrase (IP), word (WRD), syllable (SYL) and tone group (TNGP), were placed between the second and third syllables in each sentence, as shown in Table 3. The target third syllable carried a high falling tone, while the pre-boundary second syllable carried one of the falling tones, i.e. HL, H̲, ML, M̲ tones. By matching the four pre-boundary tones with the four boundaries, sixteen sentences were designed. The focus conditions of the sentences varied to include broad focus on the entire sentence, or narrow focus on the subject noun, the verb or object. However, only sentences with broad focus were analyzed. Each sentence with a different focus condition was repeated three times. Altogether 48 sentences were analyzed in Experiment 2.

Table 3. Example of corpus for Experiment 2 with boundaries between second and third syllables.

	Sentence	
IP	[a ˧ mã ˥˩, liam ˥˩ a ˧ kɔ ˥]	'Grandma, pinch aunt.'
WRD	[i ˧ lap ˥̲˩̲ a ˥˩ mɔ ˧ p^he ˧]	'He stepped on duck feather comforter.'
SYL	[ti ˧ lua ˨˩ a ˥˩ t^hau ˧ dziŋ ˧˥]	'Before the comb.'
TNGP	[a ˧ ɔk ˨̲˩̲ liam ˥˩ a ˧ kɔ ˥]	'A-ok pinched aunt.'

2.3. Instrumentation

Recordings were conducted in a sound-proof booth in the Department of Foreign Languages and Literatures at National Chiao Tung University in Hsinchu, Taiwan. A TEV TM-728II unidirectional dynamic microphone was connected to a SONY MZS-R4ST Mini Disk to record the acoustic signals. This Mini Disk did not use ATRAC compression, thus it allowed full recovery of the digital signals. The digital acoustic signals were transferred from Mini Disk to PC through an optical fiber. An ESPS x-waves program was used to generate the fundamental frequency tracks for each sentence.

2.4. Procedure

During the recording a female experimenter and a speaker were present in the booth, to carry out short dialogues to ensure that the speakers produced the

sentences in a semi-spontaneous and non-rehearsed manner. During the exchange, speakers read sentences in a random order from a written list and they waited for the experimenter to produce a precursor question, such as 'What happened?', 'Who hit grandma?', 'What did grandma do to the comb?', or 'Who did grandma hit?'.

As there were no indications of focus constituency on the reading list, speakers had to wait for the experimenter's precursor question to be able to answer using the appropriate focus condition. If the experimenter decided that the desired focus distribution had not been produced, she would repeat the precursor question, and ask for another attempt.

2.5. Data analysis

An Emu labeling program was used to display fundamental frequency (F_0) patterns, spectrograms, and waveforms and to provide a means for labeling the relevant tonal and segmental aspects of the utterances. Syllabic boundaries were determined by identifying spectrographic cues, such as the energy difference between nasals and vowels and the formant transitions between consonants and vowels. After segmenting and labelling syllable boundaries, the focus conditions for individual syllables were also tagged.

Pitch range, which has widely used to determine the effect of prosodic focus on Mandarin tones (Jin 1995; Xu 1999; Hsiong 2002; Huang 2004), was used to determine the effect of the prosodic boundary on Taiwanese tones in this investigation. Multiple time points were identified within each target syllable in order to determine the F_0 change through the syllable. In essence, a F_0 value was obtained at equidistant time points within target syllables and these points were used to determine the F_0 maximum and minimum values in each syllable.

Another Emu program (Emuquery) was used to obtain the time at the onset and offset of the second, third and fourth syllables. The duration of the target syllables was calculated by subtracting the time of the syllable onset from the time of the syllable offset. Next, the duration of each syllable was divided into eight equidistant time points from the 5%, 10%, 20%, 40%, 60%, 80%, 90% to 95% points, and the F_0 at each of these points was extracted and converted into a log value. The F_0max and F_0min log values from the eight points were taken to identify the low falling ML and M̲ tones. For high falling tones, the 5% to 20% points were rising, due to assimilation, and were not taken to be part of the high falling tones, which were taken to be defined by measurements after the 40% point. After the identification of F_0max and F_0min values, the local F_0 ranges were calculated by subtracting the F_0min values from the F_0max values.

A three-way repeated measures MANOVA (speaker × boundary × tone) was used to analyze the log F_0max, F_0min and F_0 range values in Experiments 1 and 2, respectively. In Experiment 1, 12 one-way repeated measures ANOVAs (boundary) were used to analyze effect of boundary type on the log F_0max, F_0min and F_0 range for four falling tones, for each of the three speakers separately. In Experiment 2, three one-way repeated measures ANOVAs (boundary) were used to analyze the F_0 effect of boundary type on the log F_0max, F_0min and F_0 range values of the HL tone, for each of the three speakers separately.

3. Results

3.1. Experiment 1

Results of a three-way repeated MANOVA (speaker × tone × boundary) on the F_0 contours showed that there were significant main effects of speaker ($F(16, 3032) = 113.34$, $p< .001$), boundary ($F(16, 3032) = 28.59$, $p< .001$), and tone ($F(24, 4397) = 60.84$, $p< .001$) on log F_0 values taken at eight equidistant points in time using the target syllables. There were also significant interactions between speaker and boundary ($F(32, 5592) = 9.16$, $p< .001$), between speaker and tone ($F(48, 7463) = 7.42$, $p< .001$), and between boundary and tone ($F(48, 7463) = 13.87$, $p< .001$). Due to the interaction, data cannot be averaged across either the three speakers or four tones, and 16 one-way repeated ANOVAs (boundary) were performed on them.

The mean F_0 contours for HL and H̲ tones after WRD, SYL, and TNGP produced by CYS, LWS and LYK are shown in Figure 1, while the mean F_0 contours for ML and M̲ tones are shown in Figure 2. For the HL tone, the mean F_0 peaks after TNGP and SYL boundaries were higher than the mean F_0 peaks after the WRD boundary in CYS's and LYK's data. In LWS's data, the mean F_0 peak after the TNGP boundary was higher than the mean F_0 peaks after the SYL and WRD boundaries. For the H̲ tone, the mean F_0 peaks after the TNGP boundary were the highest in the data for all three speakers. For the ML tone, the mean F_0 peaks after the three boundaries did not differ much from each other in LYK's and LWS's data (Figure 2). However, in LYK's data the mean F_0 peaks after the SYL and TNGP boundaries were higher than the mean F_0 peaks after the WRD boundary. Similarly, for the M̲ tone, the mean F_0 peaks were similar in CYS's and LWS's data; however, in LYK's data for the mean F_0 peaks after the SYL and TNGP boundaries were higher than the mean F_0 peaks after the WRD boundary.

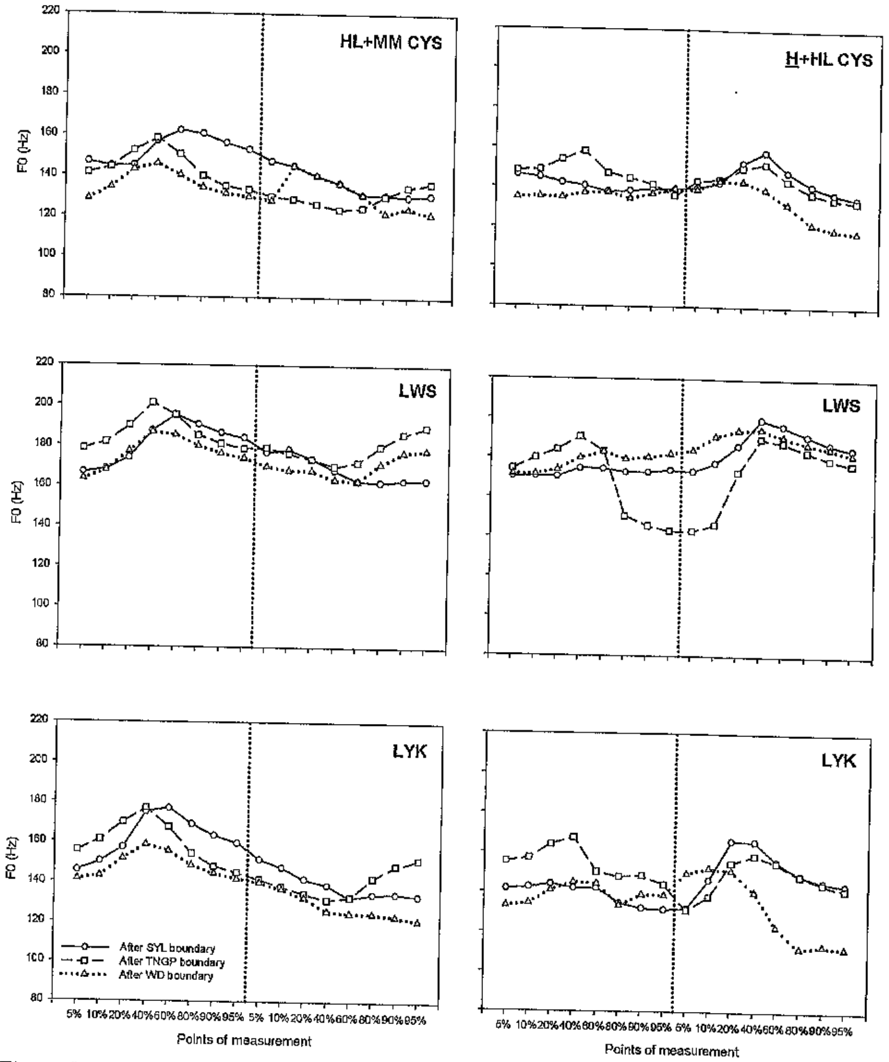


Figure 1. Mean F_0 contours for target high falling tone (HL) followed by MM tone (HL+MM condition) and target low falling tone (ML) followed by HL tone (ML+HL condition) across SYL, TNGP, and WRD boundaries produced by three speakers, CYS, LWS and LYK.

Results of 12 one-way repeated ANOVAs (boundary) and post-hoc Duncan tests are shown in Table 4. There were no significant effects of boundary type on F_0max values (corresponding to F_0 peaks) for the ML tone produced by LWS and LYK, or the M̲ tone produced by LWS. Among data sets that showed significant effects of boundary type, the ranking of F_0max values for the HL

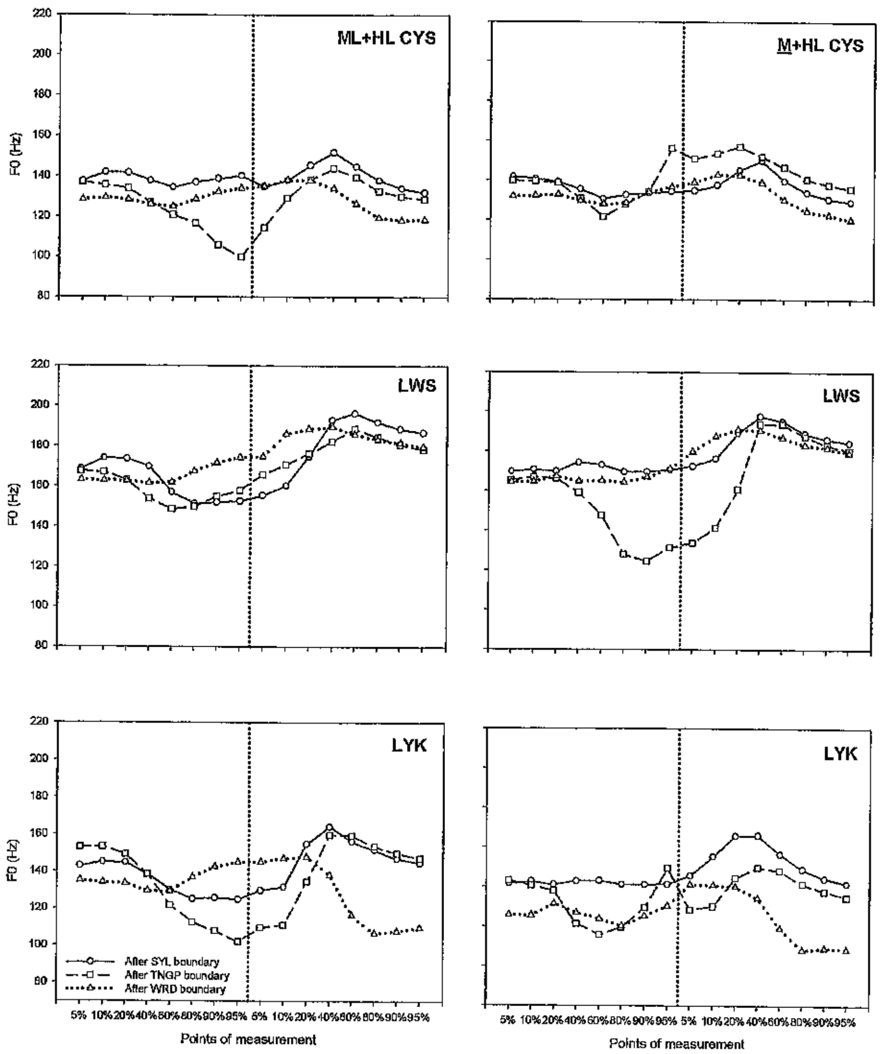


Figure 2. Mean F_0 contours for target high falling checked tone (H) followed by high falling tone (HL) in H +HL condition and target low falling checked tone (M) followed by high falling tone (HL) in M+HL condition across SYL, TNGP, and WRD boundaries produced by three speakers, CYS, LWS and LYK.

showed a trend of TNGP ≥ SYL ≥ WRD for all three speakers. For the H tone, F_0max showed a trend of TNGP > WRD ≥ SYL. For the ML tone, as there was a significant effect of boundary only on the F_0max data of CYS, no general ranking could be drawn across all the speakers. As for the M tone, the ranking

of the F_0max values showed a trend of TNGP ≥ SYL ≥ WRD in the data for CYS and LYK, but not in those for LWS.

Table 4. Results of ANOVAs (boundary) and post-hoc Duncan tests on log F_0max, *F0*min and *F0* range in Experiment 1. S: syllable, W: word, T: tone group boundary

		F_{0max}		F_{0min}		F_{0range}	
CYS	HL	F=40.47 P< .001	T=S>W	F=65.71 P< .001	S>W=T	F=37.84 P< .001	T>W>S
	H	F=50.01 P< .001	T>S=W	F= .87 P= .422		F=25.92 P< .001	T>W>S
	ML	F=9.70 P< .001	S>T=W	F=25.27 P< .001	S=W>T	F=22.18 P< .001	T>W=S
	M	F=4.53 P< .05	T>S=W	F=5.22 P< .01	S=W>T	F=15.71 P< .001	T>W>S
LWS	HL	F=12.94 P< .001	T>S>W	F=3.86 P< .05	S=T, T=W, S>W	F=23.11 P< .001	T>W=S
	H	F=14.17 P< .001	T>W>S	F=47.43 P< .001	S=W>T	F=52.09 P< .001	T>W>S
	ML	F= .60 P= .5523		F=15.16 P< .001	W>S>T	F=3.75 P< .05	T=W=S
	M	F=1.90 P= .1527		F=45.15 P< .001	S=W>T	F=25.71 P< .001	T>W>S
LYK	HL	F=30.97 P< .001	T=S>W	F=20.15 P< .001	S>W=T	F=20.58 P< .001	T>W=S
	H	F=45.73 P< .001	T>W>S	F=1.48 P= .2319		F=3.9 P< .05	T>W=S
	ML	F=2.69 P= .0714		F=14.21 P< .001	S=W>T	F=8.81 P< .001	T>W=S
	M	F=9.29 P< .001	T=S>W	F=45.63 P< .001	S>W=T	F=36.44 P< .001	T>W>S

As far as the F_0 valleys were concerned, for the HL tone, the mean F_0 valleys were the highest after the SYL boundary and lowest after the WRD boundary in all three speakers' data (Figure 2). For the H tone, there was not much difference between the mean F_0 valley after the three different boundaries in the data for CYS and LYK; however, in those for LWS, the mean F_0

valleys of the H tone were the lowest after the TNGP boundary. For the mean F_0 valleys of the ML and M tones, they were found to be the lowest after the TNGP boundary in all three speakers' data (Figure 2). The mean F_0 valleys for the M tone after the SYL and WRD boundaries clustered together in the data for CYS and LWS. In the data for LYK, the mean F_0 valley for the M tone after the SYL boundary was higher than the F_0 valleys after the WRD and TNGP boundaries.

As shown in Table 4, there were no significant effects of boundary on the F_0min (corresponding to F_0 valleys) of the H tone produced by CYS and LYK. Results of post-hoc tests revealed that among all three speakers' data, the F_0min values were the highest after the SYL boundary for the HL tone produced by all three speakers, and the M tone produced by LYK. After the TNGP boundary, the F_0min values were the lowest in the H tone produced by LWS, the ML tone produced by all three speakers, and the M tone by CYS and LWS. Generally speaking, the ranking for the F_0min values showed a trend of SYL≥ WRD ≥ TNGP.

As shown in Table 4, results of post-hoc test found that the F_0 ranges were significantly greater after the TNGP boundary than after the SYL and WRD boundaries, with the F_0 range for ML tone produced by LWS being the only exception ($p < .05$). There was also a tendency for the F_0 range to be either the smallest after the SYL boundary or as small as the F_0 range after the WRD boundary. Generally speaking the ranking for the F_0 range showed a trend of TNGP ≥ WRD ≥ SYL.

In summary, there was a trend for the F_0max to be the highest and F_0min to be the lowest after the TNGP boundary. Thus, F_0 range was the largest after the TNGP boundary. While F_0min values were the highest after the SYL boundary, the F_0max tended to be the lowest after the SYL boundary, and F_0 range was thus smallest after the SYL boundary.

3.2. Experiment 2

Turning to the restricted data on the HL tone after the WRD, SYL, and TNGP boundaries in the same position in the sentences, the results of a two-way repeated MANOVA (speaker × boundary) on log F_0 revealed that there were significant effects resulting from the speaker ($F(16, 122) = 48.64$, $p < .001$), and the boundary ($F(24, 178) = 7.31$, $p < .001$) on the F_0 values taken at the eight equidistant data points through the F_0 contours, i.e. from 5%, 10%, 20%, 40%, 60%, 80%, 90%, to 95% points in time in target syllables. Due to significant interactions between the speaker and boundary ($F(48, 304) = 2.23$, $p < .001$),

the data were not averaged across all the speakers. Instead, three one-way ANOVAs (speaker) were used to analyze individual speakers' data.

As shown in Figure 3, the mean F_0 contours were still rising to reach the H target during the initial portion of the HL tone, i.e. from 5% to 20% points. The falling contours of the HL tone did not start until after the 40% point in the syllables, and the F_0 peaks and valleys were thus located between the 40% to 95% points. As shown in Figure 3, the mean F_0 peaks after the SYL boundary were either the highest, as in the data for HHP and HSR, or as high as the mean F_0 peaks after the IP boundary, as in the data for JYZ. The mean F_0 peaks after the TNGP and WRD boundaries were lower than the mean F_0 peaks after the SYL and IP boundaries.

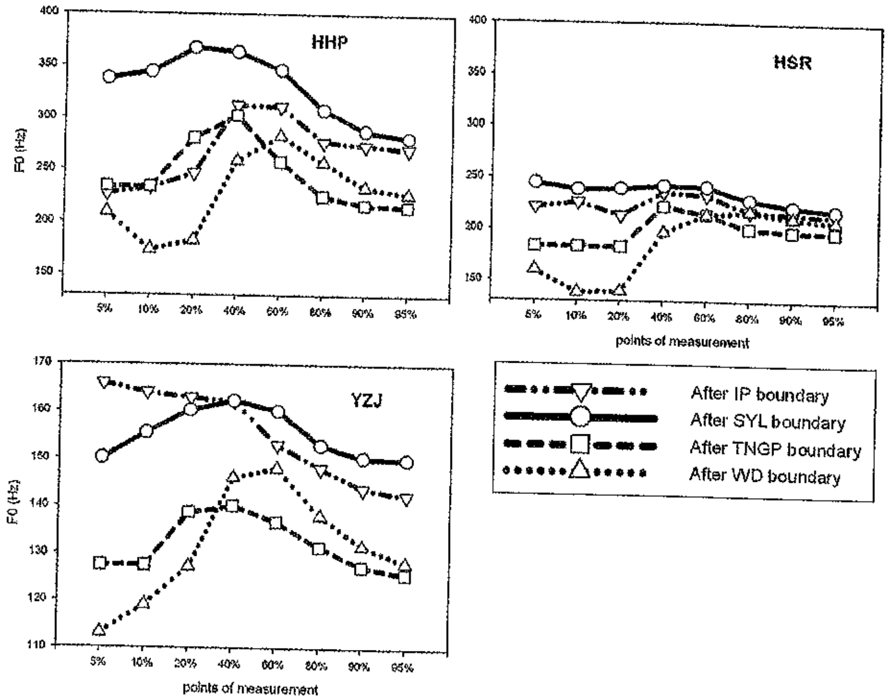


Figure 3. Mean F_0 contour for HL tone after IP, word, syllable and tone group boundaries.

Results of post-hoc tests (Table 5) revealed that the F_0max values (corresponding to F_0 peaks) after the SYL and IP boundaries were not significantly different from each other; they were higher than after the TNGP and WRD boundaries in the data of all three speakers. A comparison between F_0max value after the TNGP with that after the WRD boundaries showed that it was larger after the TNGP boundary in HHP's data, but smaller in the data for YZJ, while the two values were indistinguishable in the data for HSR.

As shown in Figure 3, the F_0 valleys were located at the 95% point for HL tone for all three speakers. There is a consistent ranking of SYL ≥ IP > WRD ≥ TNGP for the F_0 valleys. Results of three one-way repeated ANOVAs (boundary) and post-hoc tests showed that the F_0min values (corresponding to F_0 valleys) after the SYL and IP boundaries were not significantly different from each other, and were higher than after the WRD and TNGP boundaries (Table 5).

Table 5. Results of ANOVAs (tone) and post-hoc Duncan tests on log F_0max, F_{0min} and F_0 range of HL tone in Experiment 2. S: syllable, W: word, T: tone group boundary

		F_{0max}		F_{0min}		F_{0range}	
Speaker	HHP	F=15.08 P<.001	S=I>T>W	F=30.74 P<.001	S=I>W=T	F=4.8 P<.01	T>I=W=S
	HSR	F=13.11 P<.001	S=I>W=T	F=7.68 P<.001	S=I>W>T	F=.18 P=.91	
	YZJ	F=12.51 P<.001	S=I>W>T	F=20.72 P<.001	S=I>W=T	F=3.98 P<.05	T=I=W>S

Turning to the F_0 range data, the results of three one-way repeated ANOVAs (boundary) and post-hoc tests showed that there was no significant effect of boundary type on the F_0 range data for HSR. There was a trend for the F_0 range to be the highest after the TNGP boundary and the lowest after the SYL boundary.

In short, the F_0max and F_0min after the SYL and IP boundaries were higher than the F_0max and F_0min after the WRD and TNGP boundaries. There was a trend for the F_0 range to have the following rank order: TNGP ≥ IP = WRD ≥ SYL. However, due to the small amount of data on only the HL tone in Experiment 2, the ranking of the F_0 range was not as clear as in Experiment 1.

4. Discussion

This study investigated the influence of boundary type on lexical tones by measuring F_0 peaks and valleys, and local F_0 span of syllables after IP, WRD, SYL, and TNGP boundaries, at both consecutive and identical positions. The results of Experiment 1 with WRD, SYL and TNGP boundaries in consecutive position demonstrated a trend for the F_0max to be ranked TNGP ≥ SYL / WRD, while F_0min showed a rank order of SYL ≥ WRD ≥ TNGP. The rank order for the F_0 range was TNGP ≥ WRD ≥ SYL. The results of Experiment 2 with IP, WRD, SYL and TNGP boundaries at the same position showed that there was a trend for both F_0max and F_0min values to be ranked as SYL=IP > WRD ≥ TNGP. The F_0range showed a trend to be ranked TNGP ≥ WRD=IP ≥ SYL.

Comparison of results in Experiments 1 and 2 revealed some common findings. First, the ranking of F_0max does not positively correlate with boundary strength. The increase of F_0 at domain initial position has been found to be a major cue for the presence of an IP boundary along with final lengthening and pause (Cruttenden, 1997). Moreover, it has been found that the deeper the boundary, the larger the post-boundary F_0 reset. For example, partial F_0 resets are found after an IP boundary, full resets after utterance and complete resets after a paragraph boundary. The extent of reset is determined by the difference between the F_0 at the end of one boundary and the beginning of the next. Generally, this implies that syllables produced after a strong prosodic boundary will have a higher F_0max than syllables produced after a weak boundary. In the current experiment, however, the F_0max values which corresponded to post-boundary tonal reset were not ranked according to a prosodic hierarchy. Nevertheless, this lack of a hierarchical pattern in the post-boundary F_0max does not suggest a lack of hierarchical cross-boundary F_0 resets. Instead, the F_0 reset pattern might have been more clearly revealed, if the current investigation had compared the F_0 value at the end of a pre-boundary syllable with the F_0 value at the beginning of the next post-boundary syllable. In other words, there may be a hierarchical pattern of the extent of F_0 reset calculated by subtracting the F_0min of a falling tone at the offset of pre-boundary syllable from the F_0max of a falling tone at the onset of post-boundary syllable. Further cross-boundary studies are necessary to address the issue of cross-boundary F_0 reset. Second, the ranking of the post-boundary F_0min values, i.e. SYL = IP > WRD ≥ TNGP, were the opposite of the rankings of the post-boundary F_0 range values, i.e. TNGP ≥ WRD = IP ≥ SYL. It was proposed that the expansion of local F_0 was achieved consistently by the lowering of F_0 valleys. These consistent rankings of the F_0min values and the F_0 ranges across boundaries clearly support the claim that F_0 contours of Taiwanese falling tones are influenced by prosodic and tone group boundaries. Moreover, since the ranking of the F_0 range expansions after a prosodic boundary were consistently IP/WRD > SYL, there is a positive trend for F_0 range to correlate positively with the depths of the boundary.

Turning to the status of tone group boundary, it has been suggested that Taiwanese is not the only language with a constituent that does not belong to a prosodic hierarchy, but which still exerts influence upon the F_0 tonal contours and organizes the surface tonal values. For English, Gussenhoven and Rietveld (1992) reported that the domain of the intonation phrase could correspond to various prosodic levels as proposed in prosodic phonology, such that the end of the IP can coincide with an utterance in one case, but only with the end of a Phonological Phrase in another. Similarly, as mentioned in the introduction, TNGP boundaries in Taiwanese do not consistently coincide with a specific boundary in a prosodic hierarchy. Second, in the Taiwanese ToBI annotation convention, a tone tier is proposed to specify the location of a tone group boundary and the surface tones according to tone sandhi rules, while a break tier is used to tag the location of prosodic boundaries. These two tiers are apparently necessary to capture the mismatch that often occurs between the end of a tone group and the end of prosodic boundaries. Third, both perceptual and acoustic data support the independence of IP and TNGP boundaries. In English, listeners expected an increase in the extent of pre-boundary final lengthening when an IP coincided with a specific prosodic boundary (Gussenhoven and Rietveld 1992). Similarly, in Taiwanese, a TNGP occuring at word boundary resulted in an expansion of the local F_0 range of the post-boundary syllable relative to a pure word boundary (WRD).

The results presented here are compatible with previous studies that have observed the articulatory effects of boundary strength. The increase of local F_0 range and the lowering of the F_0 valleys for Taiwanese falling tones demonstrates the effect of initial strengthening after the boundary. Future research should incorporate the issues of pre-boundary lengthening, initial strengthening and cross-boundary tonal articulation to fully portray the effect of boundary strength on tonal articulation.

Notes

Thanks to Professor Anne Chao, Chih-Wei Lin and Yi-Huei Jiang for assistance in statistical analysis and Julie McGory for assistance in editing the paper.

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