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台灣華語中的語尾緊喉現象

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摘要

本研究探討語者、性別、韻基、聲調、語調對於台灣華語之語尾緊喉現象的影響。參與研究的發音人有30人，男女各半；每人均針對180句陳述句及180句疑問句進行錄音。結果顯示，聲調及語調與語尾緊喉現象有高度的相關性，但性別、語者及韻母則否。統計分析不僅支持這樣的結果，更確定了聲調及語調的互動。確切而言，在陳述句中，只有第三聲及第四聲傾向於帶有緊喉現象，而在疑問句中，聲調與緊喉並無明顯相關。本研究顯示低頻（low pitch）在緊喉現象的產生上扮演著重要的角色；而對於此影響，陳述句尾的下降語調有加乘效果，疑問句尾的上升語調則有削減的效果。另外，本研究的部份結果與多數先前文獻相佐，我們認為是聲調語言與非聲調語言之差異所造成的。

關鍵詞：緊喉、語尾、聲調、語調、台灣華語

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The Utterance-final Glottalization in Taiwan Mandarin

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Abstract

This study investigated the influence of five factors: gender, speaker, rime, tone, and intonation on the rate of utterance-final glottalization in Taiwan Mandarin. Thirty speakers, 15 male and 15 female, participated in the recording of 180 declarative and 180 interrogative sentences designed for the study. The results indicated that tone and intonation were highly correlated with utterance-final glottalization, whereas gender, speaker, and rime were not. Statistical analyses not only supported the results but also revealed the interaction of tone and intonation. To be specific, it was tone 3 and tone 4 that tended to be glottalized in declaratives. In interrogatives, by contrast, none of the tones was subject to glottalization. We thus conclude that low pitch plays a crucial role on the rate of utterance-final glottalization and this effect is magnified by the falling intonation of declaratives and minimized by the rising intonation of interrogatives. The diverse results between the current study and most previous ones may be attributed to the difference between tone and non-tone languages.

Keywords: glottalization, utterance-final, tone, intonation, Taiwan Mandarin

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1. Introduction

Glottalization, also known as creaky voice, laryngealization (Kohler, 1996; Ding, Jokisch, & Hoffmann, 2004), or vocal fry (Hollien, Moore, Wendahl, & Michel, 1966; Valley, 2010), refers to a phonation state where the vocal folds vibrate anteriorly while the arytenoid cartilages are pressed together (Ladeforged & Maddieson, 1996: 48). Acoustically, glottalization is characterized by longer or irregular glottal pulses (e.g., Pierrehumbert & Talkin, 1992; Dilley, Shattuck-Hufnagel, & Ostendorf, 1996; Huffman, 2005),[1] as exemplified in Figure 1, where the region of longer, irregular glottal pulses is indicated by the angle brackets. In contrast, a syllable with modal voice (Figure 2) does not contain such irregular pulses.

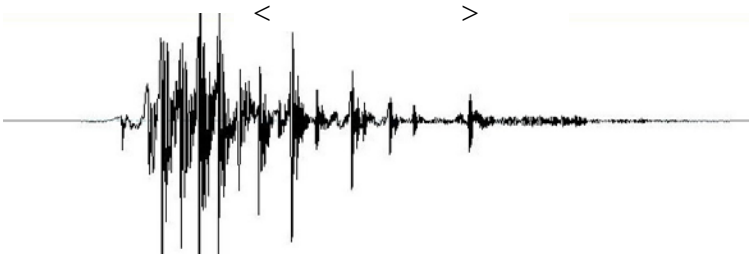

Figure 1 A Glottalized Syllable ([pa^{21}] "handle" by one of the female speakers)

[1] The term glottalization also refers to a type of secondary articulation, i.e., the complete closure of glottis accompanying the production of obstruents, plosives in particular. For example, the final /t/ of the word *bat* can be glottalized as [t^{ʔ}]. This type of articulation is also called pre-glottalization or glottal reinforcement. In the current study, the term glottalization refers only to a period of longer or irregular glottal pulses.

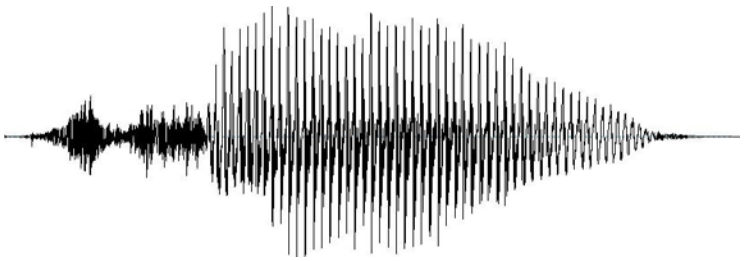

Figure 2 A Syllable with Modal Voice ([$ts^{h}a^{55}$] “to wipe” by one of the female speakers)

In terms of location, glottalization is often observed before voiceless plosives, in word-initial vowels, and in utterance-final syllables (Kohler, 1996). The glottalization before plosives arises when a plosive is produced simultaneously with a glottal stop (see footnote 1). Since the production of a glottal stop involves a continuum from glottalization to a complete glottal closure (Docherty & Foulkes, 1995; Ladeforged & Maddieson, 1996; Docherty, Foulkes, Milroy, & Walshaw, 1997), longer or irregular glottal pulses may thus be observed in the final portion of the vowel before such plosives.

The occurrence of glottalization in word-initial vowels, on the other hand, has been attributed to prosodic factors, such as the boundary of intonational phrases (Pierrehumbert & Talkin, 1992) and pitch accent (Dilley et al., 1996). Moreover, this type of glottalization may well result from the insertion of a glottal stop as a common strategy to avoid onsetless syllables (Uffmann, 2003: 4-5; Borrof, 2007; Żygis, 2010: 126-130).

Finally, glottalization in utterance-final syllables pertains to the

relaxation of our speech mechanism (Kohler, 1996: 208),[2] with increasing glottal area and decreasing subglottal pressure (Slifka, 2000, 2006). Slifka (2007) has related this phenomenon to the case of voiceless glottalized plosives and concluded that irregular phonation served as a cue to silence in speech. In a similar vein, glottalized voice has been reported to signal the end of a speaker's turn in a conversation (Laver, 1980; Local, Wells, & Sebba, 1985). In addition, utterance-final glottalization was found to function as a cue for familiar speaker recognition (Böhm, 2006; Böhm & Shattuck-Hufnagel, 2007).

Although glottalization has received considerable attention in the literature, most studies focus on non-tone languages. Given that pitch is one of the conditioning factors of glottalization (see below), how this phenomenon manifests itself in tone languages, where pitch is contrastive, is worthy of exploration. As part of the effort at a better understanding of glottalization in tone languages, this study investigated the utterance-final glottalization in Taiwan Mandarin. Specifically, it examined the effect of five possible factors, speaker, gender, tone, intonation, and vowel height, as discussed in the next section.

2. Review of Relevant Studies

2.1 Influencing Factors of Glottalization

Several factors have been reported to influence the rate of glottalization. This section presents a brief review of following factors: *speaker*, *gender*, *pitch*, and *vowel height*.

The rate of glottalization has been observed to vary across speakers. For

[2] Utterance-final glottalization may well be caused by a glottal stop inserted utterance-finally as a signal of self-interruption, which is irrelevant to the relaxation of the speech organs. Nakatani and Hirschberg (1994) termed this phenomenon as *interruption glottalization*.

instance, the five radio announcers in Dilley et al. (1996) exhibited 13% to 44% glottalization rate on word-initial vowels. The four speakers in Slifka (2000) showed 5%, 37%, 93%, and 95% utterance-final glottalization. Slifka further noted that speakers of American English seemed to have their preference for the use of glottalized voice—some preferred regular endings in phrases and utterances; others preferred irregular ones.

Gender has also been found to be one of the factors conditioning glottalization. Take British English for example; Esling (1978), Stuart-Smith (1999), Henton and Bladon (1987) reported that males used glottalized voice much more often than females.[3] This pattern can be interpreted as a representation of masculinity as glottalization is often characterized by low pitch, and men generally have lower pitch than women (Podesva, 2013: 427). However, recent studies on Northern American English (e.g., Yuasa, 2010; Podesva, 2013; Podesva & Szakay, 2013) indicated that females glottalized more than males. Yuasa (2010) suggested that this is due to the belief that glottalized voice quality sounds more professional. In this regard, this kind of gender difference reflects the social function of masculinity.

Low pitch, or fundamental frequency (F_0),[4] is another contributing factor of glottalization (Ladefoged, 1971; Pierrehumbert & Talkin, 1992). Broadly speaking, the function of F_0 is twofold. It serves as *intonation* when denoting discourse functions of phrases or utterances, and as *tone* when used to contrast lexical meanings. Therefore, the rate of glottalization can be influenced by intonation in non-tone languages and by both intonation and tone in tone languages.

[3] Esling (1978) and Stuart-Smith (1999) focused on Edinburgh and Glasgow dialects, respectively. The dialects studied by Henton and Bladon (1987) were Received Pronunciation (RP) and Modified Northern dialect.

[4] Pitch and fundamental frequency refer to the same sound attribute, the former from an auditory perspective, the latter, acoustic.

Although few studies explored the effect of vowels on glottalization, vowel height, which causes the intrinsic pitch difference, is a potential factor —high vowels have higher pitches than low vowels (House & Fairbanks, 1953; Perterson & Barney, 1952). Moreover, glottalized vowels tend to be perceived lower in quality (Brunner & Żygis, 2011). The current study investigated the effect of vowel's intrinsic pitch by testing the effect of rimes (see section 2.3).

2.2 Mandarin Tones and Intonation

2.2.1 Mandarin Tones

Mandarin Chinese has four lexical tones, as illustrated in Figure 3.[5] The tones are marked by the digits *1* to *5* (Chao, 1930), with *1* representing the lowest pitch and *5* the highest in one's pitch range. Tone 1 is high level, Tone 2 high rising, Tone 3 low dipping, and Tone 4 high falling. They can be exemplified by [ma^{55}] "mother", [ma^{35}] "numb", [ma^{214}] "horse", and [ma^{51}] "to scold", respectively.

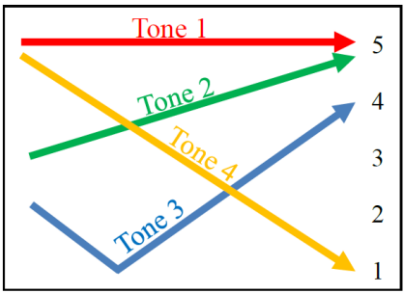

Figure 3 Mandarin Tones

[5] There is a neutral tone, often carried by the last syllable of a word or phrase (e.g., [ɕi^{51} tɕie$^{neu.}$] "details") and by most function words (e.g., [lai^{35} lə$^{neu.}$] "come ASP"). The actual pitch value of a neutral tone depends on the tone of the preceding syllable. This tone was not included in the current study because it is much less frequently used in Taiwan Mandarin (Kubler, 1981: 68).

Among the tones, Tone 3 and Tone 4 need further comments. As regards Taiwan Mandarin, studies differ in their conclusion on the contour of Tone 3. For example, Shi and Deng (2006) and Li, Xiong, and Wang (2006) claimed that Tone 3 is falling, without the rise, but Fon and Chiang (1999) and Fon et al. (2004) found that Tone 3 remained dipping. Striking as it is, the conflict may result from the studies' small sample size (no more than four speakers). A study with a larger sample size (33 speakers) was conducted by Sanders (2008), who concluded that Tone 3 was changing its contour from dipping to falling over generations in Taiwan. However, it should be noted that despite the contour variation, the production of Tone 3 still involves the lowest region of one's pitch range.[6]

As for Tone 4, it may appear as *53* before another tone, but opinions differ as to the identity of the following tone. Chao (1968: 28-29), for instance, commented that this happens before another Tone 4, whereas Shen's (1990) acoustic study revealed that Tone 4 appeared as *53* before any of the four lexical tones and as *51* before a neutral tone or in final position (see also Yip, 2002: 180; Duanmu 2007: 238). As will be seen later, the results of the current study support Shen's observation.

2.2.2 Mandarin Intonation

The intonation of Mandarin utterances can generally be categorized into *rising* and *falling*. The former is used for interrogatives without final particles and the latter for declaratives.[7] According to Chao (1933), the intonation

[6] Some studies indicated that Taiwan Mandarin Tone 2 took a dipping contour (e.g., Fon & Chiang, 1999; Fon et al., 2004). This is also subject to variation—older speakers tend to have a rising Tone 2, while younger speakers tend to have a dipping Tone 2 (Sanders, 2008). Most importantly, however, even if it is dipping, Tone 2 has a higher pitch range than Tone 3 in citation form (Sanders, 2008) and in final position (Fon et al., 2004).

[7] Typical Mandarin interrogatives are made by adding a particle (e.g., [-ma] or [-nə]) to the end of a declarative sentence. An interrogative without a final particle is referred to as a *rhetoric question*. Zeng, Martin, and Boulakia's (2004) acoustic study has revealed that both types of interrogative have higher utterance-final register than declaratives do. The register is highest in rhetoric questions.

contours are added simultaneously onto the syllabic tones of the utterances; this phenomenon was described by Chao (1968: 39) as 'small ripples (syllabic tones) riding on large waves (intonation).' This *simultaneous addition* has gained support from several acoustic studies (e.g., Shen, 1989; He & Jing, 1992; Shi, Wang, & Liang, 2009). In addition, it is the final syllabic tone that is most affected by the intonation of an utterance—the overall pitch range of the final syllable is raised in interrogatives and lowered in declaratives (e.g., M. Lin, 2006; Wang & Shi, 2010). As we will see, some of the results of the current study follow directly from this effect (section 5.3).

2.3 Taiwan Mandarin Rimes

Rime is selected as a factor in the current study for the following reasons. First, since vowel height could have an effect on glottalization, the test on different rimes includes that of vowel height. Second, Mandarin has only nasal codas [-n, -ŋ], and nasals generally have low pitches. Therefore, it is intriguing to see whether vowel-nasal combinations contribute to glottalization rate. Third, it is also interesting to see if diphthongs, which mix different vowel heights, have an effect.

Taiwan Mandarin rimes differ slightly from those of Standard Chinese,[8] which can be deduced from the 17 rhyming groups listed in Duanmu (2007: 67). The rhyming groups appear in the second column of Table 1 and the rimes are listed in the third column.[9] Pre-nuclear glides are not part of the rime (Cheung, 1986; Ao, 1992, 2002; J. Wang, 1993; Duanmu, 2007; Y. Lin, 2007).

[8] Standard Chinese here refers to *Putonghua*, the standardized Mandarin spoken in China.
[9] The glides [j, w, ɥ] before the vowels [i, u, y], respectively, result from the rule of G-spreading (Duamnu, 2007: 64-65).

Table 1
The Rhyming Groups and Rimes in Standard Chinese

NO.	Rhyming Group	Rime
1	ji	i
2	wu	u
3	ɥy	y
4	a ia wa[10]	a
5	ɤ	ɤ
6	je ɥe	e
7	wo	o
8	ai wai	ai
9	əi wəi	əi
10	au jau	au
11	əu jəu	əu
12	jin ɥin	in
13	ən wən	ən
14	an jan wan ɥan	an
15	əŋ jəŋ wəŋ	əŋ
16	aŋ jaŋ waŋ	aŋ
17	wuŋ j^{w}uŋ	uŋ

Before turning to Taiwan Mandarin rimes, two points need to be noted. First, the form *jan* in group 14 should be [jæn] (Xu, 1980) or [jɛn] (Chao, 1968). Since Duanmu adopts the form of [jæn] in other parts of the book, the transcription here is probably phonemic. Second, the syllabic approximants [z̩, z̩˞] are not included in the rhyming groups. The syllabic consonant [z̩] follows the onsets [ts, ts^{h}, s] and [z̩˞] follows [ʈʂ, ʈʂ^{h}, ʂ, z˞]. The two sounds are voiced prolongation of the onset, and they rhyme with each other.[11] Accordingly, Standard Chinese has 20 rimes (17 + [æn, z̩, z̩˞]).

[10] As Duanmu comments, this low vowel can be transcribed as [ɑ] if the default feature value for a low vowel is [+back, –round].

[11] These two syllabic consonants were also analyzed as vowels (e.g., Howie, 1976); however, more evidence indicates that they are quite different from vowels in nature. See Duanmu (2007: 34-35) for discussion.

In Taiwan Mandarin, there are a few differences. First, the rimes [əi] and [əu] sound more like [ei] and [ou], respectively, and due to the influence of Taiwanese, many speakers produce them as monophthongs [e] and [o]/[ɔ] (Kubler, 1981: 64; Y. Lin, 2007: 270). Second, the rime [uŋ] is [ɔŋ] (e.g., [tɔŋ^{51}] "to move", [jɔŋ^{51}] "to use". Third, when the rime [əŋ] is preceded by labial onsets [p, p^{h}, m, f], it also becomes [ɔŋ] (Kubler, 1981: 58), for example, [pɔŋ^{51}] "to jump", [p^{h}ɔŋ^{51}] "to touch", [mɔŋ^{51}] "dream", and [fɔŋ^{51}] "phoenix". Fourth, the forms [jæn, ɥan] are [jɛn, ɥɛn], respectively. Last, the form [jəŋ] in group 15 is [jiŋ]; this adds one more rime to the language. Consequently, Taiwan Mandarin has 21 rimes.

Other phenomena, nonetheless, complicate the picture. For example, merger has been reported in Taiwan Mandarin on the pairs [in, iŋ] (> [in]) and [ən, əŋ] (> [ən]) (e.g., Kubler, 1981: 58; Y. Lin 2007: 268-269; Hsu & Tse, 2007). Moreover, there is a strong tendency for [ʈ̻, ʈ̻^{h}, ʂ̻, ʐ̻] to lose their retroflection and are pronounced as [ts, ts^{h}, s, z] (Y. Lin, 2007: 267-268).[12] The two rimes [ʐ̩, ʐ̻] thus tend to merge into [ʐ̩]. To avoid unnecessary variance, these six rimes were excluded from the current study.[13] Therefore, the 15 Taiwan Mandarin rimes the current study employed were [i, u, y, a, o, ɤ, e, ai, ei, au, ou, an, en, aŋ, ɔŋ].

2.4 Glottalization in Mandarin

There are relatively few studies involving glottalization in Mandarin Chinese among which, to my knowledge, only two studies were targeted at glottalization production. Belotel-Grenié and Grenié (2004) found that

[12] The voiced retroflex fricative [ʐ̩] is transcribed as a post-alveolar retroflex approximant [ɹ] in Y. Lin (2007).

[13] The mergers listed here are not without variation (see, for example, Su, 2012; Tse, 1992). The point is that the mergers make the relevant rimes inappropriate for our experiment. Moreover, to avoid confusion, the transcriptions in the rest of the paper do not reflect these mergers.

Mandarin speakers used glottalization to signal a boundary between discourse units, for instance, sentences and paragraphs. However, the data were collected from only two female speakers, and their two corpora consisted of no more than 38 sentences. Ding et al. (2004), on the other hand, is a fairly detailed acoustic study. Although there were just eight speakers (four male and four females) from different regions of China, they employed a large amount of reading materials, including 400 isolated syllables (100 for each tone) and natural texts that targeted only at Tone 3. Their major findings included:

a. glottalization rate varied across speakers.

b. glottalization tended to occur in Tone 3 and Tone 4.

c. glottalization of Tone 3 arose in the middle part of the syllable and the end of Tone 4.

d. the local accent and gender had little influence on the occurrence of glottalization.[14]

These findings reflect the close relation between low pitch and glottalization.[15] Tone 3 and Tone 4 are the only two tones that involve the lowest pitch (marked with digit *1*). However, the possible influence of intonation was left unconsidered in the study.

3. Method

3.1 Speakers and Materials

Thirty speakers of Taiwan Mandarin, 15 males and 15 females, whose age ranged from 30 to 50, were recruited. They had no known hearing or

[14] The term *local accent* here refers to the regional variety of Mandarin Chinese, under the influence of the speaker's local dialect.

[15] Yu (2010) reported similar findings in Cantonese.

speaking defects, and they are all bilinguals of Mandarin and Taiwanese.[16]

Since multiple factors were involved, a factorial experiment was conducted. A total of 180 disyllabic words or phrases were selected (three words/phrases ending in each of the 4 tones from the 15 rimes: 3x4x15=180, as listed in Appendix 1.) and put in the final position of a declarative sentence: *Wo hui shuo* ____. "I can say ____." and an interrogative sentence: *Ni hui shuo* ____? "You can say ____?"; a list of 360 sentences was thus compiled. The speakers were asked to read the sentences aloud and steady at a normal speed. All the sentences were recorded by Sony ICD-SX1000 PCM recorder, and the recording was done in a quiet room.

3.2 Data Analysis

The waveforms of the recorded sound files were observed in *Praat* (Boersma & Weenink, 2013). A syllable was counted as glottalized if irregular or longer glottal pulses were observed.[17] However, a sandhi process in Taiwan Mandarin could complicate the matter. As reported in Lo (2004), many speakers in Taiwan produce utterance-final Tone 2 as Tone 3, except when the preceding syllable carries Tone 3 (e.g., [t^{h}iɛn^{55} t^{h}aŋ$^{\mathbf{35>21}}$] "paradise" but [sz̩^{21} ʂən$^{\mathbf{35}}$] "Death"). This phenomenon was also observed in some of our Tone 2 tokens. Figure 4 is an illustrative example, in which the second syllable ([ti^{35}]) has a falling contour, and the angled brackets indicate the region of glottalization. To avoid confusion, glottalization in such a syllable was not counted.

[16] Although the speakers are bilinguals of Mandarin and Taiwanese, their Mandarin is not under heavy influence of Taiwanese. In other words, the Taiwan Mandarin in this study is not the variety which Y. Lin (2007) refers to as *Taiwanese-accented Standard Chinese*, in which, for instance, the rime [iŋ] is [iəŋ].

[17] This data observation was done solely by the author.

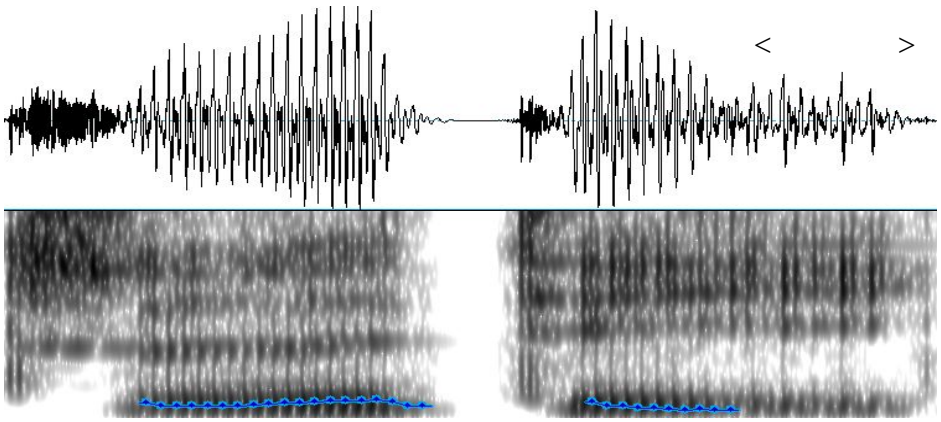

Figure 4 [ʈʂʐ^{35} ti$^{35>21}$] “recorder (instrument)” by speaker M13

The study set out to examine utterance-final syllables; in the course of analysis, however, penultimate Tone 3 and Tone 4 syllables were found to behave distinctly in regard to glottalization. Therefore, these syllables were also included in the analysis.

4. Results

4.1 Data Observation and Comparison

By comparing the number of glottalized tokens between males and females, across the speakers, and among the rimes, we can see that these three factors contributed little to the occurrence of utterance-final glottalization. As shown in Table 2, male and female speakers displayed the same glottalization rate (25%). The glottalizatin rate across speakers showed little deviation, ranging from 24% to 26%, as presented in Table 3.[18] Likewise, different rimes exhibited similar results (25%-26% in Table 4).

[18] Speakers were marked by gender and number. For example, M1 refers to male speaker NO. 1, M2 to male speaker NO. 2, F3 to female speaker NO. 3, etc.

Table 2
Number of Glottalized Tokens by Gender

	Male	Female
Declaratives	1,323	1,338
Interrogatives	23	22
Total	1346	1360
Percentage (%)	25	25

Table 3
Number of Glottalized Tokens by Speaker

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Declaratives	84	90	90	90	88	87	88	87	90	89
Interrogatives	3	1	2	3	1	3	1	1	1	1
Total	87	91	92	93	89	90	89	88	91	90
Percentage (%)	24	25	26	26	25	25	25	24	25	25
	M11	M12	M13	M14	M15	F1	F2	F3	F4	F5
Declaratives	86	88	88	88	90	90	86	88	87	89
Interrogatives	2	1	1	1	1	1	1	2	1	2
Total	88	89	89	89	91	91	87	90	88	91
Percentage (%)	24	25	25	25	25	25	24	25	24	25
	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
Declaratives	92	89	90	90	90	89	90	89	89	90
Interrogatives	2	2	1	1	4	1	1	1	1	1
Total	94	91	91	91	94	90	91	90	90	91
Percentage (%)	26	25	25	25	26	25	25	25	25	25

Table 4
Number of Glottalized Rimes

	i	u	y	a	o	ɤ	e	ai
Declaratives	182	176	178	175	175	177	177	175
Interrogatives	3	3	6	3	3	1	2	2
Total	185	179	184	178	178	178	179	177
Percentage (%)	26	25	26	25	25	25	25	25
	ei	au	ou	an	en	aŋ	oŋ	
Declaratives	176	179	174	179	176	183	179	
Interrogatives	8	2	3	2	2	2	3	
Total	184	181	177	181	178	185	182	
Percentage (%)	26	25	25	25	25	26	25	

The major influence on the rate of glottalization came from *tone* and *utterance type*. As shown in Table 5, glottalized tokens occurred much more often in declaratives (49%) than in interrogatives (0.83%). Among the four tones, glottalization tended to occur in Tone 3 and Tone 4 (49%-50%), as opposed to Tone 1 and Tone 2 (0.63%-0.78%). In addition, Tone 3 and Tone 4 appeared to be glottalized in declaratives (over 1,300), rather than in interrogatives (under 20).

Table 5
Number of Glottalized Tones

	Tone 1	Tone 2	Tone 3	Tone 4	Total	Percentage (%)
Declaratives	10	11	1,321	1,319	2,661	49
Interrogatives	7	10	18	10	45	0.83
Total	17	21	1,339	1,329		
Percentage (%)	0.63	0.78	50	49		

Figure 5 to Figure 8 below present the typical waveforms of utterance-final Tone 1, Tone 2, Tone 3, and Tone 4, respectively. In each figure, only the vowel part of the designated syllable is shown. The upper waveform was extracted from the declarative sentence and the lower from the interrogative one. As can be observed in the figures, only declarative-final Tone 3 and Tone 4 were glottalized. Further, as discovered in Ding et al. (2004), the glottalization of Tone 3 began in the middle of the syllable while that of Tone 4 arose at the end of the syllable, as observed in Figure 7 and Figure 8, where the region of glottalization is indicated by angled brackets.

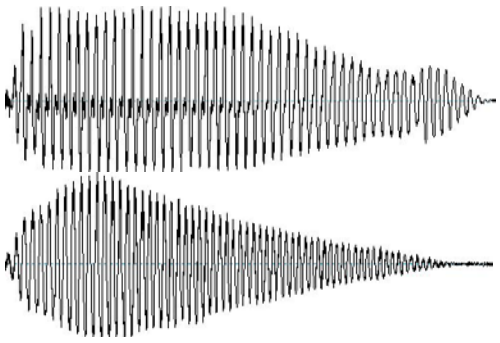

Figure 5 The Vowel of [tɕi^{55}] from [lei^{21} tɕi^{55}] "to cumulate"

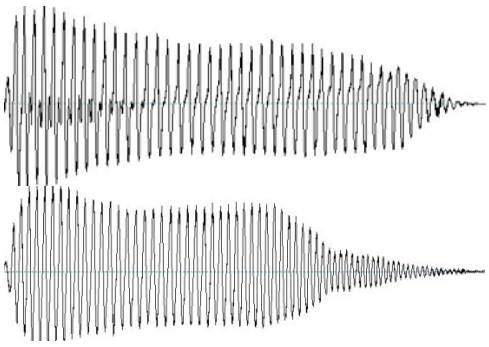

Figure 6 The Vowel of [thi^{35}] from [xɤ^{35} thi^{35}] "river bank"

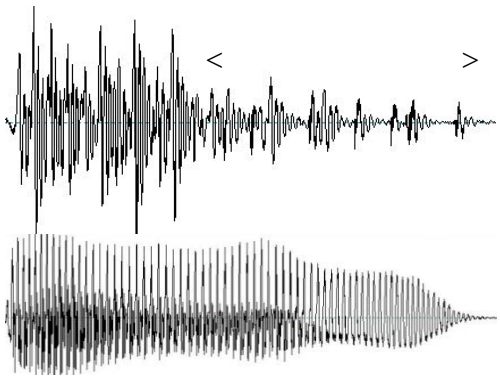

Figure 7 The Vowel of [pei^{21}] from [nan^{35} pei^{21}] "south and north"

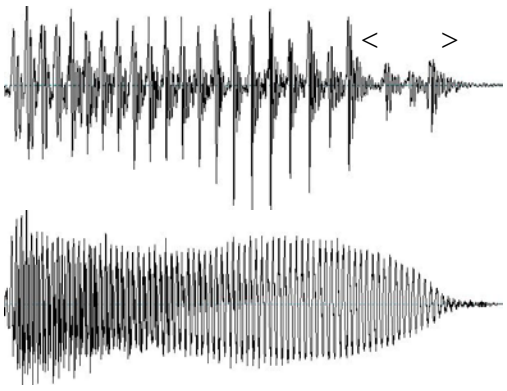

Figure 8 The Vowel of [tai^{51}] from [ɕi^{55} tai^{51}] "to carry"

4.2 Statistical Analysis

Since for each token, glottalization was either present or absent, Binary Logistic Regression was employed to see whether our results displayed

statistical significance and whether any interaction of the factor is significantly correlated with glottalization. The dependent variable was the occurrence of glottalization; the independent variables were the five factors, *gender*, *speaker*, *tone*, *rime*, *utterance type* (UType) and their interactions. Table 7 lists the effect of each factor and the interaction of *tone* and *UType*. All other factor interactions were not significant, which can be found in the table in Appendix 2.

Table 7
Partial Results of Binary Logistic Regression

Factors	Coefficient	P-value
gender	.090	.700
speaker	<.001	.993
rime	-.002	.880
tone	4.344	<.001
UType	-9.796	<.001
tone*UType	-5.309	<.001

As we can see, three of the factors, namely, *gender*, *speaker*, and *rime*, did not make significant contribution to the occurrence of glottalization ($p>.05$). On the other hand, *tone*, *UType*, and their interaction significantly contributed to glottalization occurrence ($p<.001$). The significance of *UType* means that glottalization rate were significantly different between declaratives and interrogatives. The negative *coefficient* value indicates that glottalization tended *not* to occur for the second level of this factor, that is, interrogatives. As for tone, the results failed to reveal which tone contribute to glottalization rate, hindering the interpretation of the effects of both tone and the interaction of tone and utterance type. To see the details, pair-wise comparisons were done between each level of *tone* and the interaction of *tone*

and *UType*.[19] The results are listed in Table 8 and Table 9. Table 9 only shows the significant comparisons; for the full table, see Appendix 3.

Table 8
Results of Pair-wise Comparisons (Scheffe) of tone

tone	Contrast[20]	P-value
Tone2-Tone1	.042	.999
Tone3-Tone1	4.702	<.001
Tone4-Tone1	4.419	<.001
Tone3-Tone2	4.660	<.001
Tone4-Tone2	4.377	<.001
Tone4-Tone3	.283	.685

Table 9
Results of Pair-wise Comparisons (Scheffe) of tone*UType

*tone*UType*	Contrast	P-value
Tone3(D)-Tone1(D)	8.452	<.001
Tone4(D)-Tone1(D)	8.384	<.001
Tone3(D)-Tone1(I)	9.161	<.001
Tone4(D)-Tone1(I)	9.093	<.001
Tone3(D)-Tone2(D)	8.823	<.001
Tone4(D)-Tone2(D)	8.755	<.001
Tone3(D)-Tone2(I)	8.706	<.001
Tone4(D)-Tone2(I)	8.638	<.001
Tone3(D)-Tone3(I)	8.209	<.001
Tone3(D)-Tone4(I)	8.708	<.001
Tone4(D)-Tone3(I)	8.140	<.001
Tone4(D)-Tone4(I)	8.640	<.001

Note. D and I refer to declaratives and interrogatives, respectively.

As we can see from Table 8, it was Tone 3 and Tone 4 that significantly

[19] The pair-wise comparisons were done by the *pwcompare* command of *Stata*, with the *Scheffe* method.

[20] If the *contrast* was positive, glottalization was more likely to occur in the first member of the pair. In contrast, a negative contrast value meant that glottalization tended not to occur in the first member of the pair.

contributed to the occurrence of glottalization. Table 9 goes a step further and shows that only Tone 3 and Tone 4 in declaratives made significant contribution.

The results of the statistical analysis confirmed that (a) *gender*, *speaker*, and *rime* had little influence on utterance-final glottalization, and (b) both *tone* and *UType* significantly affected the rate of utterance-final glottalization. To be specific, among all the possible *tone-UType* combinations, only Tone 3 and Tone 4 in declaratives tended to be glottalized.

4.3 Additional Findings: Penultimate Tone 3 and Tone 4

In the course of data analysis, it was observed that in declaratives, penultimate Tone 3 syllables also tended to be glottalized (94%, 1,011 out of 1,080 tokens); [21] no significant difference was found in *gender* (coefficient=.431, p=.390>.05), *speaker* (coefficient=-.006, p=.840>.05) and their interaction (coefficient=.085, p=.147>.05). In contrast, penultimate Tone 4 syllables were only sparsely glottalized (1%, 10 out of 1,050 tokens). In interrogatives, however, both of them showed low glottalization rate (Tone 3: 1.2%, 13 out of 1,080 tokens; Tone 4: 0%).

5. General Discussion

5.1 Tone and Intonation

The fact that Tone 3 and Tone 4, instead of the other two tones, tended to be glottalized suggests that a low pitch contributes to the rate of glottalization since only Tone 3 and Tone 4 involve the lowest pitch in one's pitch range, represented by the digit *1*. Moreover, glottalization in Tone 3 began in the

[21] The penultimate Tone 3s changed to Tone 2s by the Tone 3 Sandhi of Mandarin Chinese (Tone 3 → Tone 2 / ___Tone 3) were not counted.

middle of the syllable while that in Tone 4 began at the end, which coincides with the fact that the point of the lowest pitch in Tone 3 (from pitch level *2* to *1*) is reached more quickly (from the beginning of the syllable) than in Tone 4 (from pitch level *5* to *1*), as illustrated in Figure 9 below.

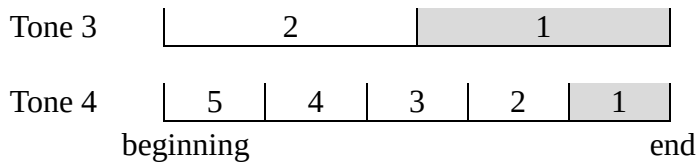

Figure 9 The Layout of Pitch Levels in Tone 3 and Tone 4 Syllables

In addition, since utterance-final Tone 3 and Tone 4 were glottalized only in declaratives, we can say that the falling intonation of declaratives magnifies the effect of low pitch on glottalization while the rising intonation of interrogatives minimizes it.

5.2 Gender, Speaker, and Rime

In the current study, neither *gender* nor *speaker* showed significant effect on utterance-final glottalization. This is inconsistent with most previous findings that glottalization tends to vary with gender and across speakers, which probably reflects the differences between tone and non-tone languages.

Since tonal contours are contrastive in tone languages, speakers, male or female, must maintain the contour of each tone to achieve successful communication. Therefore, each speaker of Mandarin needs to employ the

lowest pitch level of her or his pitch range in producing Tone 3 and Tone 4. The variation of glottalization rate with *gender* and *speaker* is thus diminished.[22]

The little effect of *rime* can be accounted for by similar argument that the intrinsic pitch difference of vowels observed in non-tone languages (House & Fairbanks 1953; Peterson & Barney 1952) is overridden by the need to maintain tonal contours in tone languages. The same need also overrode the pitch of vowel-nasal combinations and diphthongs.

5.3 Penultimate Tone 3 and Tone 4

Penultimate Tone 3 is often glottalized, whereas penultimate Tone 4 was not. Since intonation has the most influence on utterance-final syllables (Wang & Shi, 2010), it seems that the help from the falling intonation was crucial for Tone 4's glottalization. Therefore, if the digit *1* in Chinese tonal transcription represents a pitch low enough for glottalization to occur, this result supports Shen's (1990) acoustic study, which suggested that non-final Tone 4 be *53* and final Tone 4 be *51*.

6. Conclusion

This study investigated the influence of *gender*, *speaker*, *rime*, *tone*, and *intonation* on the rate of utterance-final glottalization in Taiwan Mandarin. The major findings are listed below.

a. The factors gender, speaker, and rime had no significant influence on the rate of utterance-final glottalization.

b. In interrogatives, none of the tones were subject to glottalization

[22] In this regard, the speaker variation in Ding et al.'s (2004) experiment (see section 2.4) probably resulted from the Tone 3s in the text, whose positions in sentences varied.

whereas Tone 3 and Tone 4 tended to be glottalized utterance-finally in declaratives.

c. The glottalization of Tone 3 began in the middle of the syllable while that of Tone 4 occurred at the end.

d. Penultimate Tone 3 and Tone 4 were found to act differently—Tone 3 was generally glottalized whereas Tone 4 was not.

At least four conclusions can be drawn from this study. First, low pitch plays a crucial role in the occurrence of utterance-final glottalization. Second, the falling intonation of declaratives increases the rate of utterance-final glottalization while the rising intonation of interrogatives decreases it. Third, the digit *1* in Chinese tonal transcription seems to represent a pitch low enough for glottalization to occur.

Last, the results of this study may reflect the differences between tone and non-tone languages.

Finally, two issues can be raised with respect to the limitations of the study. First, Ladefoged (1999) has pointed out that at least six speakers from each sex are required for meaningful measurements; however, statistically, the sample size of this study (15 males and 15 females) may not be large enough. Second, the recording setting with printed documents and a recorder may make the speakers subconsciously speak more formally. Since speech style is also a conditioning factor of glottaliztion (e.g., Rodgers, 1999), utterance-final glottalization may manifest itself differently in spontaneous speech. In consequence, further investigation of the phenomenon should be based on data from spontaneous speech of more speakers.

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Appendix 1: The Research Stimuli

Rime	Tone	Phrase		
i	1	tɕjaŋ ti	“lowering”	降低
		lou tʰi	“stairs”	樓梯
		lei tɕi	“to cumulate”	累積
	2	fən li	“to part”	分離
		xɤ tʰi	“river bank”	河堤
		ʈʂʐ̩ ti	“recorder”	直笛
	3	ʂən tʰi	“body”	身體
		jɔŋ tɕi	“overcrowded”	擁擠
		mau pi	“Chinese brush”	毛筆
	4	tʰu ti	“land”	土地
		pi tʰi	“nasal mucus”	鼻涕
		ʐ̩wei li	“sharp”	銳利
u	1	ʂou tu	“capital”	首都
		ʈʂʰu tsu	“to rent”	出租
		taŋ ʈʂʰu	“at that time”	當初
	2	xən tu	“crude”	狠毒
		lu tʰu	“journey”	路途
		wei lu	“to dine together”	圍爐
	3	tʰjɛn pu	“to fill”	填補
		ni tʰu	“mud”	泥土
		ɕja ʂu	“subordinate”	下屬
	4	ʈʂʰəŋ tu	“degree”	程度
		ou tʰu	“to vomit”	嘔吐
		ma lu	“road”	馬路
y	1	ku tɕy	“former home”	故居
		wei tɕʰy	“feel wronged”	委屈
		pi ɕy	“necessary”	必需
	2	jou tɕy	“post office”	郵局
		ʂəŋ ɥy	“the left”	剩餘
		jou ɥy	“because”	由於
	3	kwei tɕy	“rules”	規矩
		kɤ tɕʰy	“songs”	歌曲
		je ɕy	“maybe”	也許
	4	wan tɕy	“polite refuse”	婉拒
		jou tɕʰy	“interesting”	有趣

		fa ly	“law”	法律
a	1	xwən ta	“mixed style”	混搭
		tɕi fa	“to stimulate”	激發
		mwo tsʰa	“fiction”	摩擦
	2	ʈʂʰu fa	“punishment”	處罰
		xwo ta	“optimistic”	豁達
		tsʰau tsa	“noisy”	吵雜
	3	wo pa	“handle”	握把
		pan ma	“zebra”	斑馬
		tʰou fa	“hair”	頭髮
	4	tɕjɛn tʰa	“to trample”	踐踏
		tswo pa	“to give up”	作罷
		xɔŋ ʈʂa	“to bomb”	轟炸
o	1	fan two	“numerous”	繁多
		xwo pʰwo	“out-going”	活潑
		pʰa pʰwo	“to move up a slope”	爬坡
	2	pʰɔŋ pwo	“prosperous”	蓬勃
		tsʰjaŋ two	“to rob”	搶奪
		ji ʈʂwo	“clothes”	衣著
	3	pʰjɛn pʰwo	“biased”	偏頗
		ʂan two	“to dodge”	閃躲
		tsʰɤ swo	“bathroom”	廁所
	4	lan two	“lazy”	懶惰
		pou pʰwo	“to explode”	爆破
		kwo tsʰwo	“mistake”	過錯
ɤ	1	kʰwai ʈʂʰɤ	“express”	快車
		ʈʂʰaŋ kɤ	“to sing”	唱歌
		tjau kʰɤ	“sculpture”	雕刻
	2	ʂɤ tɤ	“willing to do sth.”	捨得
		ta ʈʂɤ	“to discount”	打折
		maŋ ʂɤ	“python”	蟒蛇
	3	ʂʐ̩ ʈʂɤ	“wise person”	智者
		la tʂʰɤ	“to pull”	拉扯
		ʂʐ̩ ʂɤ	“to give away”	施捨
	4	kɤ ʐɤ	“heat protection”	隔熱
		jiŋ ʂɤ	“to allude to”	影射
		jɛn sɤ	“color”	顏色
e	1	ɕjɛn tɕje	“to connect”	銜接
		njɛn tʰje	“to paste”	黏貼

		tsʰai tɕʰje	“to cut”	裁切
	2	li pje	“to part”	離別
		fan tɕʰje	“tomato”	蕃茄
		tɕʰiŋ ɕje	“to tilt”	傾斜
	3	xɤ tɕje	“to compromise”	和解
		piŋ tɕʰje	“and”	並且
		ʂu ɕje	“to write”	書寫
	4	kan ɕje	“to thank”	感謝
		tɕʰjaŋ lje	“strong”	強烈
		ʂʐ̩ tɕje	“world”	世界
ai	1	tɕʰjou pʰai	“bat (for sports)”	球拍
		ʈʂʰʐ̩ tai	“dementia”	痴呆
		tɕʰiŋ tʰai	“moss”	青苔
	2	pʰiŋ tʰai	“platform”	平台
		ʈʂu ʈʂai	“house”	住宅
		xwei lai	“to come back”	回來
	3	ɕja ʈʂai	“narrow”	狹窄
		tɕiŋ tsʰai	“brilliant”	精彩
		kɔŋ tsai	“action figure”	公仔
	4	ɕi tai	“to carry”	攜帶
		tʰau tʰai	“to screen out”	淘汰
		ji lai	“to rely on”	依賴
ei	1	kan pei	“bottom up”	乾杯
		tɕʰi fei	“to take off”	起飛
		la pʰei	“molding clay”	拉胚
	2	ta lei	“to thunder”	打雷
		tswo pʰei	“to accompany”	作陪
		tau tsei	“thief”	盜賊
	3	pau lei	“fortress”	堡壘
		nan pei	“south and north”	南北
		tʰu fei	“bandit”	土匪
	4	lau lei	“tired”	勞累
		ʈʂwən pei	“preparation”	準備
		fən pʰei	“to distribute”	分配
au	1	lau tau	“to nag”	嘮叨
		pʰwo tʰau	“ocean waves”	波濤
		ta lau	“to get out of water”	打撈
	2	pʰan tʰau	“to defect”	叛逃
		ɕin lau	“toil”	辛勞

		laŋ ʈʂʰau	“ocean waves”	浪潮
	3	tɕʰiŋ tau	“to dump”	傾倒
		tɕi tʰau	“to beg”	乞討
		ku lau	“ancient”	古老
	4	ʈʂʰɤ tau	“traffic lane”	車道
		tɕje tʰau	“to solve problems”	解套
		fan tsau	“restless”	煩燥
ou	1	ɕjau tʰou	“thief”	小偷
		ʈʂən sou	“to search”	偵搜
		xwei ʂou	“to recycle”	回收
	2	kʰɔŋ tʰou	“to air-drop”	空投
		kau lou	“high building”	高樓
		ʈʂʰəŋ ʂou	“mature”	成熟
	3	fa tou	“to shiver”	發抖
		ʈʂu lou	“bamboo basket”	竹簍
		tɕiŋ tsou	“walking race”	競走
	4	ta tou	“to fight”	打鬥
		ʈʂʰwan tʰou	“to penetrate”	穿透
		faŋ lou	“leak-proof”	防漏
an	1	ʈʂʰəŋ tan	“to be responsible”	承擔
		fən tʰan	“to share loads”	分攤
		wu tsʰan	“lunch”	午餐
	2	mjɛn tʰan	“interview”	面談
		tsʰai lan	“basket”	菜籃
		tjɛn zan	“to ignite”	點燃
	3	ta tan	“brave”	大膽
		mau tʰan	“woolen blanket”	毛毯
		tjɛn lan	“cable”	電纜
	4	xwa tan	“young female role”	花旦
		kan tʰan	“to sigh”	感嘆
		tsʰan lan	“splendid”	燦爛
ɛn	1	kʰɔŋ tɕjɛn	“space”	空間
		pʰaŋ pjɛn	“nearby”	旁邊
		ɕin ɕjɛn	“fresh”	新鮮
	2	jou ɕjɛn	“leisurely”	悠閒
		ɕin njɛn	“new year”	新年
		ʂəŋ tɕʰjɛn	“money-saving”	省錢
	3	tɕje tɕjɛn	“economical”	節儉
		ʈʂɔŋ tjɛn	“key point”	重點

		tɕiŋ ɕjɛn	“dangerous”	驚險
	4	fa ɕjɛn	“to discover”	發現
		faŋ pjɛn	“convenient”	方便
		lai tjɛn	“incoming call”	來電
aŋ	1	tan taŋ	“responsibility”	擔當
		nɔŋ tʰaŋ	“thick soup”	濃湯
		fən faŋ	“aromatic”	芬芳
	2	kʰɤ tʰaŋ	“class”	課堂
		ʈʂaŋ laŋ	“cockroach”	蟑螂
		tʰi faŋ	“river bank”	堤防
	3	tsu taŋ	“to block”	阻擋
		pʰiŋ taŋ	“to lie down”	平躺
		mwo faŋ	“to imitate”	模仿
	4	pai taŋ	“to swing”	擺盪
		fa tʰaŋ	“burning hot”	發燙
		tɕje faŋ	“to release”	解放
ɔŋ	1	ɕjaŋ tʰɔŋ	“to figure out”	想通
		xan tɔŋ	“cold winter”	寒冬
		ʂʐ̩ ʈʂɔŋ	“clock”	時鐘
	2	ɕjaŋ tʰɔŋ	“identical”	相同
		tɕi lɔŋ	“place name”	基隆
		fu tsʰɔŋ	“to abide by”	服從
	3	ma tɔŋ	“toilet”	馬桶
		pjɛn ʈʂɔŋ	“mutant”	變種
		ʈʂou ʈʂʰɔŋ	“to receive favor”	受寵
	4	ʈʂən tɔŋ	“to shake”	震動
		piŋ tʰɔŋ	“sickness”	病痛
		tʰi ʈʂɔŋ	“body weight’	體重

Appendix 2: The Results of Binary Logistic Regression

Factors	Coefficient	P-value
gender*speaker*tone*rime*UType	-.011	.627
gender*speaker*tone*rime	-.012	.250
gender*speaker*tone*UType	.120	.229
gender*speaker*rime*UType	-.007	.698
gender*tone*rime*UType	-6.02	.147
speaker*tone*rime*UType	.064	.157
gender*speaker*tone	-.007	.882
gender*speaker*rime	-.007	.349
gender*speaker*UType	.027	.731
gender*tone*rime	.044	.659
gender*tone*UType	-.130	.881
gender*rime*UType	-.131	.425
speaker*tone*rime	.002	.671
speaker*tone*UType	-.039	.424
speaker*rime*UType	.005	.613
tone*rime*UType	.351	.455
gender*speaker	.008	.793
gender*tone	-.197	.636
gender*rime	-.006	.929
gender*UType	.384	.576
speaker*tone	.021	.367
speaker*rime	.002	.649
speaer*UType	-.046	.231
tone*rime	.033	.171
rime*UType	-.047	.232
tone*UType	-5.309	<.001
gender	.090	.700
speaker	<.001	.993
rime	-.002	.880
tone	4.344	<.001
UType	-9.796	<.001

Appendix 3: The Results of the Pair-wise Comparison of tone*UType

*tone*UType*	Contrast	P-value
Tone3(D)-Tone1(D)	8.452	<.001
Tone4(D)-Tone1(D)	8.384	<.001
Tone3,(D)-Tone1(I)	9.161	<.001
Tone4(D)-Tone1(I)	9.093	<.001
Tone3(D)-Tone2(D)	8.823	<.001
Tone4(D)-Tone2(D)	8.755	<.001
Tone3(D)-Tone2(I)	8.706	<.001
Tone4(D)-Tone2(I)	8.638	<.001
Tone3(D)-Tone3(I)	8.209	<.001
Tone3(D)-Tone4(I)	8.708	<.001
Tone4(D)-Tone3(I)	8.140	<.001
Tone4(D)-Tone4(I)	8.640	<.001
Tone4(D)-Tone3(D)	-.068	>.999
Tone1(I)-Tone1(D)	-.709	.943
Tone2(D)-Tone1(D)	-.371	.998
Tone2(I)-Tone1(D)	-.254	>.999
Tone3(I)-Tone1(D)	.243	>.999
Tone4(I)-Tone1(D)	-.256	>.999
Tone2(D)-Tone1(I)	.338	>.999
Tone2(I)-Tone1(I)	.455	.997
Tone3(I)-Tone1(I)	.952	.716
Tone4(I)-Tone1(I)	.453	.997
Tone2(I)-Tone2(D)	.116	>.999
Tone3(I)-Tone2(D)	.614	.945
Tone4(I)-Tone2(D)	.115	>.999
Tone3(I)-Tone2(I)	.497	.976
Tone4(I)-Tone2(I)	-.001	>.999
Tone4(I)-Tone3(I)	-.499	.975