INTERSPEECH 2016
September 8–12, 2016, San Francisco, USA

Coda Stop and Taiwan Min Checked Tone Sound Changes

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Abstract

This acoustical and Electroglottography (EGG) study investigates the effect of coda deletion and co-articulatory phasing on vowels and final coda stops, [p t k ʔ], in Taiwan Min checked tones 3 and 5 syllables. Vowel duration, f0, spectral tilt (H1*-A3*), cepstral peak prominence (CPP) and glottal contact quotient (CQ_H) were analyzed. Compensatory lengthening, f0 lowering and increasing periodic phonation during the production of vowels after coda deletion were observed. During gradual phasing when codas were produced as energy damping, the vowels were found to be shorter in duration and less periodic in voicing than vowels abruptly phased with coda that were produced as full stop closure. However, spectral tilt H1*-A3* was not affected by either coda deletion or co-articulatory phasing. Therefore, these findings suggest that H1*-A3* may play a salient role in checked tone identification, and, as a result, is unaffected by sound change.

Index Terms: *coda deletion, co-articulatory phasing, vowel duration lengthening, f0 lowering, voicing periodicity, glottal contact quotient*

1. Introduction

Taiwan Min, also known as Taiwanese Hokkien or Taiwanese, is spoken by approximately 70% of the population in Taiwan. It belongs to the Min-Nan (Southern Min) branch of Chinese Min and is unintelligible to the speakers of Mandarin, Hakka, and Formosan Austronesia languages on the islands.

There are seven lexical tones in Taiwan Min, including five unchecked tones (55, 13, 53, 31 and 33) occurring in a CV(N) syllable structure and two checked tones (5 and 3) occurring in a CV[p, t, k, ʔ] syllable structure [1], [2]. The number in the tonal naming scheme represents pitch; the higher the number, the higher is the pitch [3].

The vowels of unchecked tones are longer in duration than those of checked tones. Checked tones 3 and 5 exhibit a glottalized voice quality which sets them apart from unchecked tones 55, 13, 51, 31, and 33 which exhibit modal voicing [1], [2], [4], [5], [6]. Following from the work of Ladefoged [7], the term ‘glottalization’ has been employed as a general term for non-modal phonation with a stiffened vocal fold phonation. According to Titze [8], glottalization is a “transient sound(s) that result from the relatively forceful adduction or abduction during phonation.”

Previous articulatory studies using fiber optics have indicated an adduction of ventricular folds during the production of Taiwan Min checked tone CV [p t k ʔ] syllables in citation form [4]. When checked tones are produced in a sentence or in a phrase, a ventricular fold incursion can be observed. Additionally, an inverse-filtered oral airflow study found that some speakers of Taiwan Min produced checked tones with small amounts of airflow and a longer closed phase [5].

In addition to the articulatory data, it has been noted that the vowels of tone 5 are produced with a longer CQ_H, a lower H1*-A3* and a higher CPP [9]. The spectral measure, H1*-A3*, is the amplitude difference between the first harmonic and the strongest harmonic during the third formant. The spectral tilt, H1*-A3*, reflects the abruptness with which the airflow is cut off when the glottis closes [10]. The asterisks indicate the corrected values of the formants and bandwidths after the influence of a low F1 on H1 has been taken into account [11]. As the magnitude of the first harmonic is affected by both the source and formant locus, when only the source signal properties are relevant, as in this study, some adjustments using an algorithm for corrected spectral tilt, H1*-A3*, are required [12], [13]. CPP measures the prominence of cepstral peaks that emerge against the overall normalized “background noise” [14], [15]. The higher the CPP value, the more periodic is the voice quality.

1.1. Coda deletion

Pan [9] replicated the findings of previous field work, which first noted sound changes among tone 5 [16] [17] [18], [19], and discovered that a final coda can be realized as a full oral / glottal stop closure, an energy dip, an aperiodic voicing, or a coda deletion at the end of a vowel. Over 80% of /ʔ/ codas and less than 20% of /p t k/ codas were deleted. Undeleted /p t k/ codas were more likely to be produced with a full stop closure among tone 3 and sandhi tone of which the surface tone differs from the underlying phonemic tone [9].

Although vowel lengthening, f0 lowering, and phonation de-glottalization were individually reported in previous field work findings [17], [18], [19], it is highly likely that these seemingly unrelated sound-change phenomena may all be related to coda deletion.

1.1.1. Vowel lengthening

The increase of vowel duration [16], [17], [18], [19] observed during Taiwan Min checked tone sound change may be related to compensatory lengthening which involves the deletion of one segment and is accompanied by the lengthening of another in a CVC syllable structure [20]. For example, in Ket [20] and Tehrani Farsi [21], the deletion of glottal segments /h/ or / ʔ / triggered the lengthening of the preceding vowels.

Coda deletion may lead to both vowel compensatory lengthening and syllable structural change from CV[p, t, k, ʔ] closed syllable to CV open syllable. It is well attested that vowels in open syllables are cross-linguistically longer than vowels in closed syllables [22], [23]. Thus, the change from a

  http://dx.doi.org/10.21437/Interspeech.2016-597

close syllable to an open syllable structure may indirectly results in vowel lengthening as well.

1.1.2. Pitch lowering

The lowering of f0 observed with tone 5 may also be related to coda deletion. The influence of a voiceless coda can be observed to raise or lower the pitch of the preceding vowels. For example, in Arabic, a non-tonal language, Hombert and Ohala [24] found that at 70 ms before a vowel offset, the f0 increased by 9 Hz before glottal stops [ʔ] and decreased by 25 Hz before the glottal fricative [h].

Similarly, in Taiwan Min the f0 during vowel production may rise before glottalized coda stops. However, the f0 increase in Taiwan Min CV [ʔ] syllables may decreased after deletion of [ʔ] as the source of co-articulatory f0 increase removed.

1.1.3. Vowel deglottalization

A non-modal voice quality may result from the transfer of the laryngealization / glottalization feature from a coda stop to a preceding vowel [25]. For example, it has been proposed that English vowel glottalization may result from the co-articulation of the glottalization coda stops and preceding vowels [26].

If the glottalized voice quality were transformed from coda stops to preceding vowels, after coda deletion, the glottalization effect may be removed. By comparing the CQ_H, H1*-A3*, and CPP of vowels in syllables with and without coda stops, the effect of coda deletion on Taiwan Min checked tone voice quality should be revealed.

1.2. Co-articulation: Abrupt and gradual phasing

In addition to the effect of coda deletion, co-articulatory phasing may affect vowels as well. According to DiCanio [27] the abrupt and gradual phasing between glottalized codas and preceding vowels results in different surface realizations of codas (Figure 1). It is proposed that when abrupt phasing occurs (Figure 1a), glottal consonants surface with a closure-like stop (Figure 2a); however, when gradual phasing occurs (Figure 1b), coda stops may surface as energy damping at the end of preceding vowels (Figure 2b). During gradual phasing between coda stops and vowels, the f0 and voice quality of vowels preceding coda stops are affected more than they are during abrupt phasing when there is less co-articulation between the vowel and following coda stop.

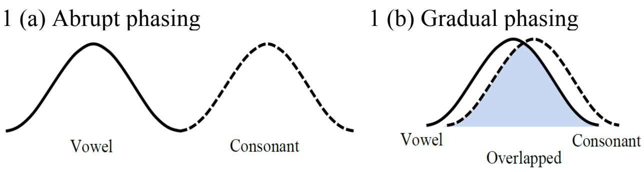

Figure 1: *(a) The abrupt phasing between vowel target and glottal gesture; (b) The gradual phasing between vowel target and glottal* gesture.

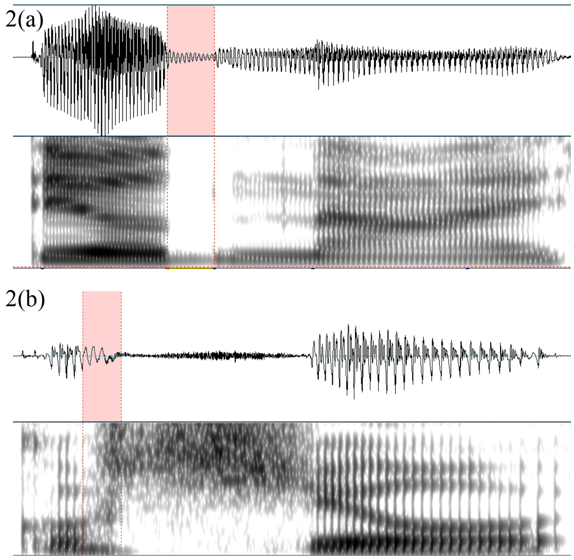

Figure 2: *(a) [tek5 nã13] "bamboo forest" coda produced as stop, (b) [kok5 sio51] "elementary school", coda produced as energy damping* .

Pan (in press) categorized coda realizations by using spectrographic visualization conducted by a group of four trained phoneticians. Each sound file was inspected by at least two phoneticians. As shown in Figure (2a), vowels in Taiwan Min checked tone CV[p, t, k, ʔ] syllables produced as full stop closures (abrupt phasing) were observed to be longer in duration and less glottalized in voice quality than were vowels in syllables with coda stops produced as energy damping (gradual phasing) as shown in Figure (2b).

1.3. Research question

In sum, this study explores how deletion and co-articulatory phasing may affect vowel duration, f0 and phonation by addressing the potential inter-correlation between the deletion of the post-vocalic voiceless consonant and (1) compensatory lengthening, (2) pitch lowering, and (3) deglottalization during the production of vowels.

It is also proposed, depending on co-articulatory phasing, that vowels before codas realized as full stop closures (abrupt phasing) are longer in duration and less glottalized than vowels overlapped with codas realized as energy damping (gradual phasing).

2. Method

2.1. Participant

Speakers were selected from the five major dialectical regions on the west coast of Taiwan: Northern Zhangzhou, Northern Quanzhou, Central Zhangzhou, Central Quanzhou and Southern Mixed [19] [28]. From each of the five dialectical regions, eight native speakers were recruited, including two females and two males aged in their twenties, and two females and two males above forty years of age. In all, 40 speakers participated (2 males + 2 females) × 2 age groups × 5 dialectical regions. All the participants spoke Taiwan Min as their native tongue at home. With the exception of one young male speaker from central Quanzhou, all the speakers had lived in their native dialectical regions until they were 16 years of age. All participants also spoke Mandarin.

2.2. Materials

Speakers were asked to produce two repetitions of 236 disyllabic words that form a tone sandhi group and that were embedded in the carrier sentence ‘Please listen to the tone of __ first.’ The carrier sentences consisted of surface tone 33. Each speaker produced 472 sentences in total. The target syllables included 184 surface tone 5 and 234 surface tone 3 samples.

2.3. Experimental Procedure

Speakers first read the order number for each sentence and then paused before reading the sentence. The recording lasted approximately 35 minutes. Speakers were asked to pause after every hundredth sentence to have a drink of water before continuing. An experimenter was with the speaker in the recording room to monitor the EGG and acoustic signals and to indicate errors to the speakers.

2.4. Instruments

The Glottal Enterprise EGG system (EG2-PCS) picked up the EGG signals from two electrodes placed on each side of each subject’s neck around the thyroid cartilage, while a TEV Tm-728 II microphone placed 15 cm from each speaker’s mouth picked up the acoustic sound waves produced during their speech. The recorded EGG and acoustic signals were simultaneously transferred to a laptop using Audacity software. Next, the EGG and acoustic data were preprocessed using EggWorks [29], while Praat was used for the manual transcription of the sound waves. F0 was analyzed using the STRAIGHT algorithm [30] and both the EGG and sound waves were analyzed together with VoiceSauce [31] to extract vowel durations, f0, CQ_H, H1*-A3* and CPP at each 10% increment.

2.5. Data analysis

Chi-square models were conducted to explore the effects of coda deletion and co-articulatory phasing. For measures indicating a significant effect of coda deletion or co-articulatory phasing categorization, linear mixed effect models with both speakers and lexical items treated as random factors were used to analyze the direction of contrast on vowel duration, f0 onset at 20% vowel intervals, f0 offset at 80% vowel intervals, the mean CPP and mean CQ_H averaged across every 10% vowel intervals.

3. Result

3.1. Effect of coda deletion

3.1.1. Duration

The result of a Chi-square showed an effect of coda deletion on duration (χ^2=1862.4, p < 0.001). Moreover, a linear mixed effect model revealed that vowel duration was significantly longer in syllables produced without coda stops (β = -36.589, p < 0.001). As a consequence it is proposed that there is a compensatory lengthening during vowel production after a coda deletion. Furthermore, after a coda deletion, in contrast to vowels in CV[p, t, k, ʔ] closed syllables, vowels in CV open syllables were lengthened.

3.1.2. F0 onset and offset

The results of the Chi-square analysis further revealed the significant effects of coda deletion on f0 onset, f0 offset and CPP (Table 1); thus, only these three measures were further analyzed using linear mixed effect regression models. As shown in Table 2, with the exception of the f0 offset of tone 3 produced by female speakers, the f0 onsets and f0 offsets of tones 3 and 5 were significantly lower in syllables with the final coda deleted. It is proposed that since tones 3 and 5 were short in duration, the f0 rise associated with glottalized coda stops to preceding vowels may have affected the entire duration of vowels. After the removal of the coda stop, the f0 rise effect was eliminated from both the f0 onset and f0 offset. Thus, a lowering in f0 was observed in both f0 onset and offset.

		Surface tone 5		Surface Tone 3	
		χ^2	p	χ^2	p
F0 onset	F	5.436	*	6.400	*
	M	51.471	***	25.225	***
F0 offset	F	8.647	**	1.625	0.202
	M	46.855	***	37.743	***
CPP	F	12.038	***	9.085	**
	M	104.122	***	123.759	***
H1*-A3*	F	1.121	0.290	0.753	0.386
	M	1.960	0.162	0.043	0.835
CQ_H	F	0.008	0.93	3.369	0.066
	M	2.210	0.137	1.329	0.249

Table 1: *Chi-square analysis (coda deletion) on surface tones 3 and 5. F: Female, M: Male, *: < .05, **: < .01, ***: < .001*

			β	t value	Pr(>|z|)	Coda
F0 onset	F	3	2.478	2.531	*	Delete<Undeleted
	F	5	2.653	2.335	*	Delete<Undeleted
	M	3	3.473	5.033	***	Delete<Undeleted
	M	5	6.286	7.217	***	Delete<Undeleted
F0 offset	F	3	1.835	1.306	0.192	
	F	5	3.626	2.951	**	Delete<Undeleted
	M	3	9.202	6.825	***	Delete<Undeleted
	M	5	9.807	6.963	***	Delete<Undeleted
CPP	F	3	-0.370	-3.090	**	Undeleted<Delete
	F	5	-0.382	-3.499	***	Undeleted<Delete
	M	3	-1.311	-11.467	***	Undeleted<Delete
	M	5	-1.123	-10.358	***	Undeleted<Delete

Table 2: *Linear mixed effect regression models (coda deletion) on surface tones 3 and 5. F: Female, M: Male, *: < .05, **: < .01, ***: < .001*

3.1.3. Phonation

In addition to compensatory lengthening and f0 lowering, a change in phonation may also be observed. As shown in Table 1, although coda deletion did not affect either H1*-A3* or CQ_H, it did affect the CPP of tones 3 and 5 which were produced by both male and female speakers. After a coda deletion, the CPP increased significantly, suggesting a more periodic voicing. In other words, in terms of phonation, only the CPP values increased after a coda deletion, while the H1*-A3* and CQ_H values remained unaltered.

In sum, though coda deletion, duration lengthening, f0 lowering and deglottalization have been previously and individually reported in different fieldwork studies [15], [16], [17], [18]. This study further confirms that duration lengthening, f0 lowering and increase in voicing periodicity are all related to coda deletion.

3.2. Effect of coarticulatory phasing

After determining the effect of coda deletion on duration, f0 and phonation, further studies of data with coda stops produced as either a full stop closure (abrupt phasing) or energy damping (gradual phasing) are needed. The effects of coda realization on duration and phonation were also investigated in this study.

To explore how coda stops and vowel co-articulatory phasing may influence phonation during Taiwan Min checked tones, this study compares the overlapped portion of vowels (represented in grey in Figure 1b) against the abruptly phased vowels and coda stops that were produced as full stop closures (Figure 1a). During abrupt phasing the vowel and coda stop did not overlap.

3.2.1. Duration

The results of the Chi-square analyses confirmed the significant effect of coda realization on duration (χ^2 =17.202, p<0.001 ***). Vowels before codas produced as full stop closures (abrupt phasing) were significantly longer than those before codas produced as energy damping (gradual phasing) (β=2.310, p<0.001***). It is proposed that there is considerably more overlapping between vowels and subsequent coda stops during gradual phasing. This overlap may shorten vowel duration significantly during gradual phasing.

3.2.2. Phonation

As shown in Table 3, co-articulatory phasing affects both CPP and CQ_H, but not H1*-A3*. As shown in Table 3, it was found that during gradual phasing, the CPP and CQ_H during final portion of the vowels that overlapped with coda stops (VCg) were lower than those taken during abrupt phasing when the production of vowels (Va) not overlapped with coda stops (Ca). It is proposed that during abrupt phasing when a vowel does not overlap with coda stops, vowel phonation is more periodic and the contact phase longer. During gradual phasing when the final portion of vowels overlaps with the coda stops, phonation is less periodic and the glottal wave contact quotient was shorter.

		3		5	
		Va-VCg	Ca-VCg	Va-VCg	Ca-VCg
CPP	F	***	*	***	*
	M	***	**	***	n.s
H1*-A3*	F	n.s	n.s	n.s	n.s
	M	n.s	n.s	n.s	n.s
CQ_H	F	***	***	***	***
	M	***	***	***	***

Table 3: *Results of linear mixed effect (phasing). Va: vowel during abrupt phasing, Ca: Coda stop during abrupt phasing, VCg: overlapped vowel and coda stops during gradual phasing.n.s.: not significantly different from each other.*

		Surface tone 5		
		χ^2	p	result
Cpp	F	51.989	***	Ca,VCg<Va
	M	42.054	***	Ca,VCg<Va
CQ_H	F	97.057	***	Ca<VCg<Va
	M	777.767	***	Ca<VCg<Va
		Surface Tone 3		
Cpp	F	43.740	***	Ca<VCg<Va
	M	41.517	***	Ca<VCg<Va
CQ_H	F	102.363	***	Ca<VCg<Va
	M	97.217	***	Ca<VCg<Va

Table 4: *Results of Chi-square analyses (phasing). F: Female, M: Male, *: < .05, **: < .01, ***: < .001, VCg: Vowel and Coda overlap (gradual phasing). Va:Vowel during abrupt phasing. Ca: Coda stop during abrupt phasing.*

4. Discussion

A longer vowel duration, a lower F0 and more periodic voicing after a coda stop deletion confirm that coda deletion contributes to compensatory lengthening, f0 lowering and phonation deglottalizating. The less periodic phonation and shorter glottal contact quotient suggest more glottalized phonation during the final portion of vowel that is gradually phased with coda stops. In sum, coda realizations indeed influence duration, f0 and phonation of preceding vowels.

The spectral tilt H1*-A3* is the only parameter not affected by coda realization. It is proposed that the abruptness of glottal closure may perceptually be the most salient cue to glottalized phonation. As a consequence, it remains robust and unaffected by coda deletion or VC co-articulatory phasing. Further tone identification studies on checked tones with various spectral tilt values are necessary before one can pinpoint accurately the salient role played by H1*-A3* during checked tone identification.

5. Acknowledgements

This study was supported by the Ministry of Science and Technology, (NSC 98-2401-H-009-040-MY3). This study was also made possible through the generosity of UCLA Phonetics Lab for permitting access to VoiceSauce and EggWorks software. Finally, gratitude needs to be expressed to Shao-ren Lyu, Ning Chang, Mao-hsu Chen, Fang-Yi C, Chia-Jou Liu, and Yi-chu Ke for their assistance in data analysis.

6. References

[1] R. L. Cheng, "Tone sandhi in Taiwanese," *Linguistics,* vol. 6, no. 41, pp. 19–42, 1968.

[2] R. L. Cheng, "Some notes on tone sandhi in Taiwanese," *Linguistics*, vol. 11, no. 100, pp. 5–25, 1973.

[3] Y. R. Chao, *A Grammar of Spoken Chinese*. Berkeley: University of California Press, 1968.

[4] R. Iwata, M. Sawashima, and H. Hirose, “Laryngeal adjustments for syllable-final stops in Cantonese,” *Annual Bulletin Research Institute of Logopedics and Phoniatrics*, no. 15, pp. 45–54, 1981.

[5] H. H. Pan, “Voice quality of Amoy falling tones,” *The Journal of the Acoustical Society of America*, vol. 90, no. 4, pp. 2345, 1991.

[6] H. H. Pan, ”Voice quality of falling tones in Taiwan Min,” *Proceedings of Interspeech 2005*, pp. 1401–1404, 2005.

[7] P. Ladefoged, “Features of the larynx,” *Journal of Phonetics,* vol. 1, no. 1, pp. 73–83, 1973.

[8] I. R. Titze, “Definitions and nomenclature related to voice quality,” in *Vocal Fold Physiology: Voice Quality control*, O. Fujimura and M. Hirano Eds. San Diego: Singular Publishing, 1995, pp. 335–342.

[9] H. H. Pan, “Glottalization of Taiwan Min checked tones,” *Journal of International Phonetic Science,* in press.

[10] K. N. Stevens and H. M. Hanson, “Classification of glottal vibration from acoustic measures,” in *Vocal Fold Physiology: Voice Quality control*, O. Fujimura and M. Hirano Eds. San Diego: Singular Publishing, 1995, pp. 147–170.

[11] H. M. Hanson, *Glottal Characteristics of Female Speakers*, Ph.D. dissertation, Harvard, USA, 1995.

[12] M. Iseli and A. Alwan, “An improved correction formula for the estimation of harmonic magnitudes and its application to open quotient estimation,” *Proceedings of the International Conference on Acoustics, Speech, and Signal Processing* (ICASSP’04), vol. 1, pp. 669–672, 2004.

[13] M. Iseli, Y. L. Shue, and A. Alwan, “Age, sex and vowel dependencies of acoustic measures related to the voice source,” *The Journal of the Acoustical Society of America*, vol. 121, no. 4, pp. 2283–2295, 2007.

[14] J. Hillenbrand, R. A. Cleveland, and R. L. Erickson, “Acoustic correlates of breathy vocal quality,” *Journal of Speech and Hearing Research*, vol. 37, pp. 769–778, 1994.

[15] D.H. Klatt and L.C. Klatt, “Analysis, synthesis and perception of voice quality variations among male and female talkers,” *Journal of the Acoustical Society of America*, vol. 87, no. 2, pp. 820–856, 1990.

[16] J. C. Liao, *台語入聲調之現況分析 (Investigation on the Entering Tones in Taiwanese)*, MA thesis, National Hsinchu University of Education, Taiwan, 2004.

[17] S. C. Chen, “台灣閩南語元音系統及陰陽入聲調的變異與變化—台灣閩南語的字表調查分析 (The vowel system changes and the Yin-/Yang-entering tonal variations in Taiwanese Hokkien),” *Journal of Taiwanese Language and Literature*, vol. 3, pp. 157–178, 2009.

[18] S. C. Chen, “台灣閩南語新興的語音變異：台北市、彰化市及台南市元音系統與陽入原調的調查分析 (New sound variation in Taiwan Southern Min: Vowel System and the lower register entering tone in Taipei, Changhua and Tainan,” *Language and Linguistics*, vol. 11, no. 2, pp. 425–468, 2010.

[19] U. J. Ang, *音變的動機與方向：漳泉競爭與台灣普通腔的形成* (*The Motivation and Direction of Sound Change: On the Competition of Minnan Dialects Chang-chou and Chuan-chou, and the Emergence of General Taiwanese*), Ph.D. dissertation, National Tsing Hua University, Taiwan, 2003.

[20] D. Kavitskaya, *Compensatory Lengthening: Phonetics, Phonology, Diachrony*. London and New York: Routledge, 2002.

[21] A. Darzi, “Compensatory lengthening in Modern Colloquial Tehrani Farsi,” *Studies in the Linguistic Sciences*, vol. 21, no. 1, pp. 23-37, 1991.

[22] I. Maddieson, “*Phonetic cues to Syllabivication*,” in *Phonetic Linguistics: Essays in Honor of Peter Ladefoged*, V. A. Fromkin Eds. Orlando: Academic Press Inc, 1984, pp. 203-221.

[23] A. C. H. Rietveld and U. H. Frauenfelder, “The effect of syllable structure on vowel duration,” *Proceedings of the Eleventh International Congress of Phonetic Sciences*, pp. 28-31, 1987.

[24] J. M. Hombert and J. J. Ohala, “Historical development of tone pattern,” in *Papers from the Third International Conference on Historical Linguistics*, J. P. Maher, A. R. Bomhard and E. F. K. koerner, Eds. Hamburg: John Benjamins Publishing Company, 1997, pp. 75-84.

[25] I. Maddiseon and P. Ladefoged, “Tense and lax in four minority languages of China,” *UCLA Working Papers in Phonetics*, vol. 60, pp. 59-83, 1984.

[26] M. Huffman, “Segmental and prosodic effects on coda glottalization,” *Journal of Phonetics,* vol. 33, no. 3, pp. 335-362, 2005.

[27] C. T. DiCanio, “Coarticulation between tone and glottal consonants in Itunyoso Trique,” *Journal of Phonetics,* vol. 40, no. 1, pp. 162-176, 202.

[28] U. J. Ang, “台灣地區閩南語的方言類型與方言區分 (On the dialect typologies and isoglosses of Taiwan Min),” *Journal of Taiwanese Languages and Literature*, vol. 3, pp. 239-309, 2009.

[29] H. Tehrani, EggWorks, 2010. This is available online at http://www.linguistics.ucla.edu/faciliti/facilities/physiology/EGG.htm. (last viewed 15/03/2016).

[30] H. Kawahara, I. Masuda-Katsuse, and A. Cheveigné, “Restructuring speech representations using a pitch-adaptive time-frequency smoothing and an instantaneous-frequency-based F0 extraction: Possible role of a repetitive structure in sounds,” *Journal of Speech Communication*, vol. 27, no. 3, pp. 187-207, 1999.

[31] Y. L. Shue, P. Keating, C. Vicenik, and K. Yu, “VoiceSauce: A program for voice analysis,” *Journal of the Acoustical Society of America*, vol. 126, pp. 2221. This is available online at http://www.ee.ucla.edu/~spapl/voicesauce. (last viewed 15/03/2016).