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# Consonant-Tone Interaction and Glottalization in Thai

## 1. Introduction

(1) Goals
  a. To show that voiced stops and voiceless unaspirated stops in Thai are glottalized via results from an acoustic study.
  b. To show that the phonology is sensitive to this – it explains consonant-tone restrictions in Thai.

(2) Overview
  a. Section 2 introduces the motivation for this study and summarizes previous research.
  b. Section 3 summarizes the experimental design.
  c. Section 4 lays out the results of the experiment.
  d. Section 5 discusses the implications of the results.
  e. Section 6 is the conclusion.

## 2. Background

(3) Thai has 5 contrastive tones (Abramson, 1962):

| **Tone** | **Phonetic Description** |
|---|---|
| High | Rising from mid to high. |
| Mid | Level mid, falling slightly at the end. |
| Low | Level low, falling slightly at the end. |
| Rising | Rising from low to high. |
| Falling | Falling from high to low. |

(4) Thai Consonant Inventory:

| | Labial | Alveolar | Palatal | Velar | Glottal |
|---|---|---|---|---|---|
| Stop | pʰ p b | tʰ t d | | kʰ k | ʔ[1] |
| Affricate | | | t͡ʃʰ t͡ʃ | | |
| Fricative | f | s | | | h |
| Nasal | m | n | | ŋ | |
| Trill | | r | | | |
| Lateral | | l | | | |
| Glide | w | | j | | |

(5) Voiced and voiceless unaspirated stops have been described as involving glottal constriction:
  a. Voiceless Stops:

[1] Glottal stop onsets are often described as the lack of an onset phonologically. Phonetically, they are pronounced as glottal stops though.

i. Abramson (1962:4): "pre-vocalic /p t k/ are pharyngealized".
ii. Harris (1972:11) labels the unaspirated series as glottalized; describes them as "pronounced with simultaneous oral and glottal closure... so that the glottal release is not heard".
iii. Gandour & Maddieson (1976:244) conclude that the voiceless unaspirated series are tense stops.

b. Voiced Stops:
i. Harris (1972:14): "utterance initial voiced stops and approximants are usually preceded by weak glottal closures"
ii. Ladefoged & Maddieson (1996:55): voiced stops occur with "stiff, or even creaky voice" and "are often accompanied by downward movement of the larynx that make them slightly implosive".

(6) Generalization: Consonant-Tone Interaction[2]:
a. Unaspirated stops, voiced stops, [ʔ] and [h] never precede high tone vowels, except in loans and onomatopoeia in open CV: syllables (Ruangjaroon, 2006; Slayden, 2011).

(7) Laryngeal features in consonants are known to interact with tone on adjacent vowels.
a. Halle & Stevens (1971) posited [slack vocal cords] to explain both voicing in obstruents and low tone on vowels.
b. Bradshaw (1999) posited [L/voice] similarly, explaining the affinity between voicing & low tone.

(8) [Constricted Glottis] and [Spread Glottis] also interact with tone, but unlike [voice], not in a consistent way cross-linguistically.
a. Ruangjaroon (2006) and Lee (2008) posit constraints banning [–Spread Glottis] preceding high tone to explain the Thai high tone ban.
b. Lee (2008) notes that [+Constricted Glottis] in a preceding consonant can neutralize high tone to low tone in Burmese, but also it neutralizes low tone to high tone in Mulao.
c. Downing and Gick (2001) presented evidence of two sets of aspirated stops in Botswana Kalang'a and two similar sets of fricatives in Nambya, one of which acted as a tone depressor, while the other did not, suggesting that spread glottis can also have two different effects on tone.

(9) Previous phonetic studies on effects of consonants on F0:
a. Hombert et al (1979) showed that voiced stops lower F0 significantly in a variety of tonal (i.e. Yoruba) and non-tonal (i.e. English, Arabic) languages.
b. However, in comparing the effect of aspirated and unaspirated voiceless stops in Thai on F0, Erickson (1975) found 8 of 11 speakers to have higher F0 following aspirated stops, but the reverse in the other 3 speakers.
c. Gandour (1974) on the other hand, found lower F0 following aspirated stops compared to unaspirated stops for all his Thai speakers.

[2] Ignoring effects of codas, which also interact with tones, complicating the picture. By inspecting open monosyllables, the coda effect is removed.

(10) Glottal constriction can be articulated in more than one way, with different effects on F0.
  a. Esling & Harris (2005) and Edmondson & Esling (2006) describe two modes of glottalized voicing:
    i. creaky voice, which they note is associated with lower F0.
    ii. harsh voice, which they note is associated with higher F0.
  b. Kingston (2005) distinguishes two kinds of glottal constriction:
    i. creakiness, which lowers F0.
    ii. tenseness, which raises F0.

(11) *Which* type of glottal constriction, if any, is present in Thai voiced and unaspirated stops?
  a. In Thai, if the phonological high tone ban with glottalized stops is mirrored in the phonetics, we would expect the creaky kind rather than the tense/harsh kind.
  b. Alternatively, the phonetic facts might diverge, and we might find evidence for the tense/harsh kind.

(12) While previous studies measured F0 only, there are other acoustic correlates of glottal constriction:
  a. Gordon & Ladefoged (2001) identify jitter and spectral tilt.
  b. Jitter is a measure of the variation in the time between glottal pulses.
    i. Glottal constriction causes a decrease in the regularity of glottal pulse periods, thus increasing jitter in voicing with creaky voice.
  c. Spectral tilt is a measure of the difference in amplitude between higher formants and a harmonic of F0.
    i. Modal voicing has relatively greater concentration of energy in F0 and relatively less in higher formants.
    ii. Creaky voicing has relatively more energy in higher formants.
    iii. I follow Keating & Esposito (2007) in calculating spectral tilt via the difference between the amplitude of the first harmonic of F0 (H1) and the amplitude of the first formant (A1).
    iv. Creaky voicing is therefore characterized by relatively low spectral tilt.

(13) Measurements of jitter, spectral tilt and F0 are taken at the start of the vowel following the consonant as measures of glottalization.
  d. Coarticulation from the consonant should yield values that reflect the effect of the glottal constriction on the consonant (if any).

**3. Experimental Design**

(14) The following experiment is designed to assess what kind of glottalization, if any, is present in voiceless unaspirated & voiced stops.

(15) The experiment consists of recording sessions where a Thai speaker reads Thai sentences containing a given test stimulus with 8 repetitions.
  a. The test stimuli were chosen with bilabial onsets [pʰ, p, b, m] to minimize lingual effects on the following vowel quality.
  b. [ʔ] and [h] onsets were also included because they involve glottal articulation.
  c. The long low vowel [aː] was used in all stimuli.

d. Test stimuli were CV: open monosyllables.
e. All possible combinations of tone and onset were varied (yielding 30 stimulus items), with 8 repetitions each.
f. In cases where no Thai word exists, a nonce word was included.
   i. For each nonce word, a Thai word with the same tone, onset & vowel quality, but with a glide coda [w, j] and/or a short vowel were recorded in addition.
   ii. In case the nonce words gave the speakers some problems, these words with glide codas would be used instead (as long as the coda and vowel length didn't affect the measured variables).

(16) I followed Morén & Zsiga (2004) in placing stimuli in host sentences.
a. All words are placed in positions where they will receive stress.
b. The sentence type that will be used is illustrated below with [pʰa:] "take" as the inserted monosyllable.

nít bɔ̀k na: <u>pʰa:</u> kʰɯ: kamtɔ̀p
Nit tell Naa <u>take</u> be answer
"Nit told Naa that "<u>take</u>" was the answer"

c. Filler stimuli (from Slayden, 2011) were also included that contained non-bilabial or non-glottal onsets and vowels other than [a].
   i. These sometimes included coda consonants as well.
   ii. They were randomly selected from Slayden's (2009) online dictionary database.

(17) The sentences were translated into Thai script.

(18) Three native male Thai speakers were recruited via social networking.

(19) The tokens were randomly ordered and presented to the subjects, who read them aloud while being recorded in a sound-proof booth at Rutgers University.

(20) Following the Recording session, the test stimuli were segmented in order to allow a Praat script (based on diCanio, 2007) to extract the measurements.
a. The script extracted measurements for jitter, spectral tilt and F0 via Praat (Boersma & Weenink, 2005).

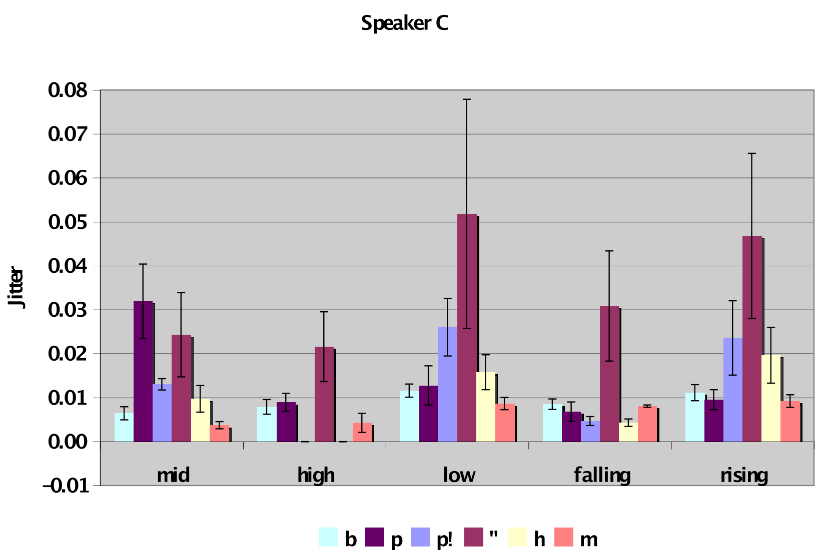
(21) Measurement details:
a. Jitter is measured as an average over the first 75 ms of the vowel.
   iii. Praat has 5 different algorithms for jitter – I used jitter (rap).
b. Spectral Tilt is measured by extracting the value of H1 – A1 from the first tenth of the vowel duration (following Keating & Esposito, 2007).
c. F0 is measured every 10 ms for the entire length of the vowel.

## 4. Results

(22) Spectral tilt & F0 results suggested that [b] and [p] are glottalized, but jitter results were not significantly different among the stops.

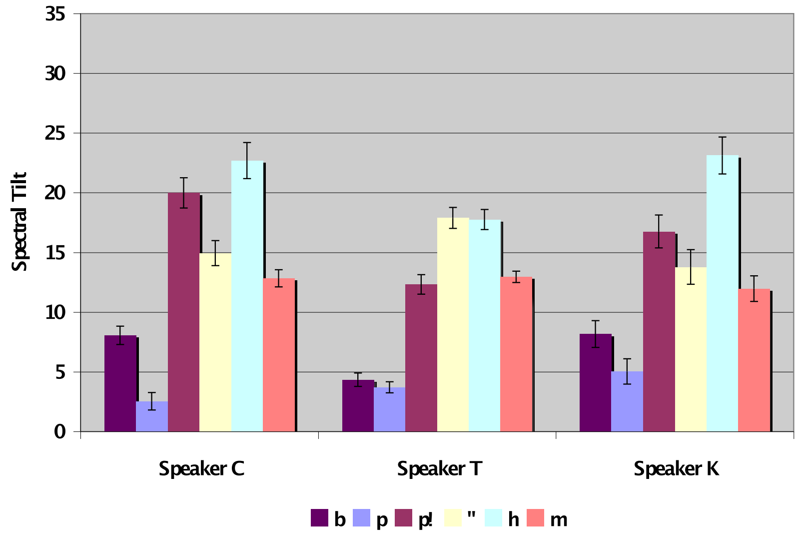
(23) Jitter

a. Main effects of Onset-type, tone and speaker were discovered for jitter.
b. No significant differences among the oral stops ([pʰ, p, and b]).
c. [ʔ] has higher jitter than [h] (but not [p]).
d. [m] has consistently lower jitter than the obstruents in all tones but falling.




(24) Spectral Tilt

a. Main effects for spectral tilt were discovered for Onset & Speaker but not Tone.
b. A 3-way distinction was discovered among the stops: [pʰ] > [b] > [p].
    i. [p] has a greater degree of glottal constriction than [b].
c. Spectral tilt following [ʔ] is significantly higher than [b] and [p].
    i. Indicates that [ʔ] has a different kind of glottal constriction than [p] and [b] ([ʔ] is not inducing creaky voice).




(25) Fundamental Frequency (F0)

a. Both [b] and [p] have lower F0 than [pʰ].

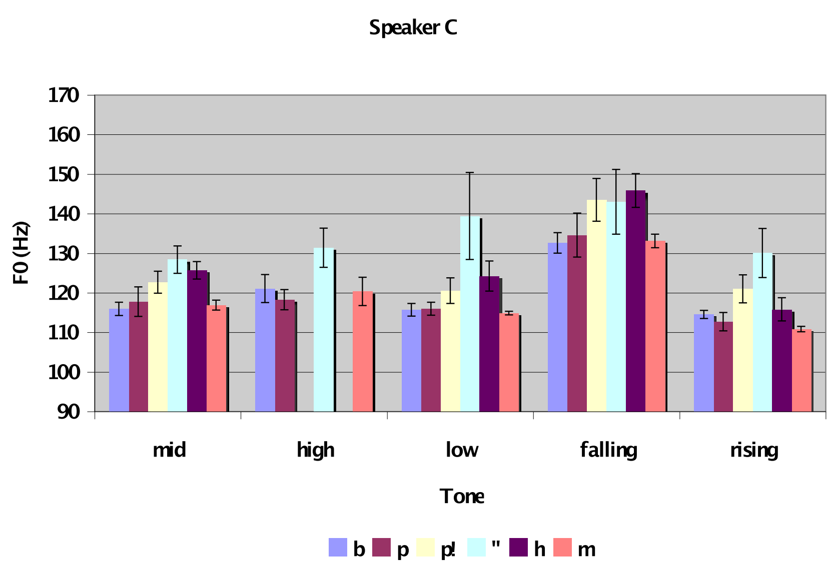
b. [ʔ] has higher F0 than all oral stops.

i. Just like spectral tilt: [ʔ] does not induce creakiness, while [b] and [p] do.

c. [m] has lower F0 than [pʰ].

i. However, [m] did not have lowered spectral tilt.

ii. Sonorants can sometimes lower F0 (Hombert et al, 1979).




## 5. Discussion

(26) Main result: Voiced and voiceless unaspirated stops have lower F0 and lower spectral tilt, indicating they are produced with glottal constriction.

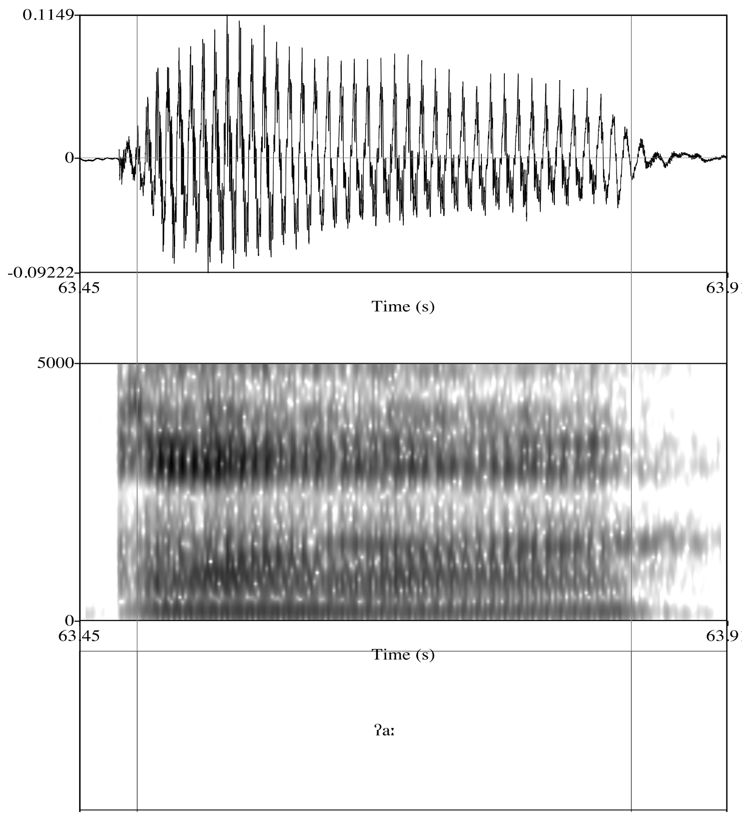
(27) The results for jitter & F0 diverge from the spectral tilt results for [ʔ] and [h].

i. ʔ > h for both jitter & F0.

    ii. h > ʔ for spectral tilt.
    iii. Therefore there are at least two independent dimensions.
  b. [h] can be isolated as the source of the difference:
    i. Breathiness is known to lower F0 but raise spectral tilt.
    ii. [h] being breathy explains this.

(28) [ʔ] had relatively higher jitter & F0, and moderate spectral tilt.
  a. [ʔ] does not cause creakiness (or spectral tilt would be lower).

b. Additionally, [ʔ] has a sharp vertical boundary at the onset of the word, indicating the release of the glottal stop, as can be seen below.
   i. This is not seen in creaky glottal stops.




c. Tense vocal folds cause raised F0 (Halle & Stevens, 1971) indicating that [ʔ] in Thai is tense.
   i. Alternatively, following Esling & Harris (2005) and Edmondson & Esling (2006), this is the kind of glottalization associated with "harsh voice".
d. Jitter and F0 correlate with tenseness while spectral tilt does not.

(29) Spectral tilt was significantly different in all 7 statistical comparisons made among onset types, whereas F0 was only significantly different in 5 of 7 comparisons (i.e. [p] vs. [b] – both glottalized, but to different degrees).
a. This resolution difference might be because Thai is a tone language.
b. F0 effects of onset consonants in non-tonal languages were found to be both larger and lasting over a longer duration by Hombert et al (1979).
c. Since Thai has tonal contrasts, speakers control F0 to a greater degree, masking the phonetic effects of onsets.
d. Spectral tilt is not involved (directly) in any contrast in Thai, and so it is not controlled to the same extent as F0.

(30) Phonological Implications:

a. Lee (2008) & Ruangjaroon (2006) use [–Spread Glottis] as the active feature in the high tone ban, since this feature picks out the class of unaspirated and voiced stops.

b. However, the results indicate that in fact, voiced stops involve glottal constriction that results in creakiness on a following vowel.

  i. Therefore, [+Constricted Glottis] is the active phonological feature in the ban.

    a. The Optimality Theoretic constraint *[+C.G.] H is the active constraint then, and not *[–S.G.] H, as in Ruangjaroon (2006) and Lee (2008).

  ii. Thai was cited by Lee (2008) as the only language in which [–Spread Glottis] was active in consonant-tone interaction.

## 6. Conclusion

(31) Voiced and voiceless unaspirated stops in Thai are accompanied with a greater degree of creaky voice at the onset of a following vowel, indicating they are produced with glottal constriction.

a. Voiced and voiceless unaspirated stops are [+Constricted Glottis].

(32) Spectral tilt & F0 results but not jitter results support this conclusion.

(33) Spectral tilt differs from F0 and jitter in its general increased sensitivity to glottal constriction in Thai.

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