

CONSONANT-TONE INTERACTION IN THAI

By

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ABSTRACT OF THE DISSERTATION

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This dissertation establishes that phonological consonant-tone interaction occurs in a non-local configuration in Thai, in contrast to current theories where this interaction is only thought to occur locally. A phonological account posits that in bimoraic unchecked syllables, tones associated with the second mora, and not the first mora, interact with onset consonants in Thai. This is implemented via an Optimality-theoretic markedness constraint, $*[+CG]_{\mu 2}[-H]$. Evidence for this position comes from a quantitative lexical gap study and a pair of judgment experiments, which show that both rising tone and high tone are ungrammatical in unchecked syllables with laryngealized obstruent onsets. In Thai, these tones share a common high-tone target at the end of the syllable. These facts suggest the presence of a phonological constraint violated by onset-tone sequences, where the tone on the second mora is referenced, despite the fact that it is the more

distant of the two. This constraint is grounded since it is phonologically less marked for tones to be realized late in syllables – the second mora is treated as the “head” mora of the syllable in Thai.

This phonological analysis is supported via evidence from an acoustic study of voiced and unaspirated obstruent onsets in Thai. It is discovered that these obstruents are articulated with laryngeal constriction, and that they form a natural class under the feature [+constricted glottis]. A second important contribution of the acoustic study was that [ʔ] onsets are phonetically distinct (they raise F0 and spectral tilt), even though they are part of the same phonological [+constricted glottis] class.

Two judgment experiments confirm the psychological reality of the constraint *[+CG]-[H]_{μ2} among native Thai words. However, three of four onset-tone sequences that violate this constraint are considered grammatical under interpretation as English loans. This result is consistent with findings in other languages, where loan strata are more permissive than native strata. In addition, participants exhibited preferences for [+constricted glottis] onsets and low tone that cannot be explained via language experience. Therefore, it is argued that the relative ranking of markedness constraints can distinguish between grammatical forms, a finding that replicates previous experiments in English and Hebrew.

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Chapter 1 – Introduction

Locality is a much-discussed topic in phonological phenomena involving relations between segments such as vowel harmony and consonant harmony (Gafos 1996; Baković 2000; Hansson 2001; Rose & Walker 2004; Nevins 2010); however research on consonant-tone interaction has relatively little discussion on the nature of locality. The major theoretical finding of this dissertation is that consonant-tone interaction in Thai occurs non-locally. This differs from previous accounts of consonant-tone interaction, where it was assumed to be strictly local (Bradshaw 1998; Lee 2008; Tang 2008). This dissertation offers experimental evidence that supports a phonological analysis where onset consonants in Thai interact with tones on the second mora, at the right edge of the syllable, but not with tones on the first mora; this constitutes a non-local interaction.

Previous accounts of consonant-tone interaction in Thai (Ruangjaroon 2006; Lee 2008) focused on a lexical gap where high tone is unattested following voiced and unaspirated onset consonants. However, this dissertation offers evidence that, in addition to high tone, rising tone is also ungrammatical following voiced and unaspirated onset consonants, as confirmed via the presence of a lexical gap (Chapter 2) and via a judgment experiment (Chapter 4). This finding has important implications for a phonological analysis of Thai. Notably, high and rising tone share a late H-tone target, a fact that sets them apart from falling tone, which has an early H-tone target. The fact that falling tone (HL) can occur following [+CG] onsets in Thai, but that high (assumed to be a mid-high sequence, following Morén & Zsiga 2006) and rising tone (LH) cannot, requires a non-local interaction between onsets and tones. This situation is illustrated in (1) below.

(1) Locality in Consonant-Tone Interaction in Thai Unchecked Syllables

a. Falling Tone	b. High Tone	c. Rising Tone
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> H μ $C_{[+CG]}$ V </div> <div style="text-align: center;"> L μ V </div> </div>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> μ $C_{[+CG]}$ V </div> <div style="text-align: center;"> H μ V </div> </div>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> L μ $C_{[+CG]}$ V </div> <div style="text-align: center;"> H μ V </div> </div>
Grammatical	Ungrammatical	

As mentioned, the two ungrammatical sequences share a common phonetic characteristic: They both have *late* H-tone targets. On the other hand, the falling-tone sequence involves an early H-tone target. This is an apparent contradiction under an assumption where moraic locality determines which tone will interact with that consonant, as is assumed in previous theoretical accounts of consonant-tone interaction (Bradshaw 1999; Lee 2008; Tang 2008)

In order to solve this apparent contradiction, a phonological constraint is posited, $*[+CG] \text{--} [H] \mu_2$, that explicitly bans H autosegments associated to the second mora in a syllable with a voiced or unaspirated onset consonant. This constraint is motivated by a cross-linguistic tendency for pitch targets to be realized late in syllables (Cutler & Chen 1997; Xu 1999, 2004). As such, the second mora is treated as the “head tone” of the syllable, with the incompatibility between $[+CG]$ onsets and H-tone involving only the second mora, and not the first mora.

The phonological analysis was supported by evidence from a quantitative lexical gap study (Chapter 2), an acoustic study (Chapter 3), and a pair of judgment experiments

(Chapter 4). The acoustic study showed that voiceless and voiced obstruents in Thai are both produced with laryngeal constriction, suggesting they form a natural class. The fact that F0 and spectral tilt are significantly lower following voiced and voiceless obstruents implies that they are both [+constricted glottis]. Previous accounts (Ruangjaroon 2006; Lee 2008) assumed that consonant-tone interaction in Thai involves the feature [–spread glottis] in onset consonants. Lee (2008) notes that Thai would have been the only language in his cross-linguistic survey that involves [–spread glottis]. The acoustic results here suggest instead that Thai fits into an already well-represented group of languages where [+CG] is incompatible with H tone.

A second contribution of the acoustic study concerns the nature of laryngeal constrictions in Thai and a mismatch between the phonetic facts and the phonological facts. While the laryngealized [+CG] obstruents involve lowered F0 and spectral tilt, [ʔ] actually involves raised F0 and spectral tilt. This phonetic finding is unexpected given that [ʔ] and the laryngealized obstruents are both incompatible with H tone. This mismatch implies that the feature [+CG], which includes both [ʔ] and the laryngealized obstruents, is abstracting across different physiological configurations of laryngeal constriction. Thus, while the physical complexity of the larynx allows for a rather large number of contrasts to be made in language (see Esling & Harris 2005 and Edmondson & Esling 2006), languages do not necessarily make use of this potential for contrast. In Thai, we see two distinctive phonetic classes of laryngeal constriction lumped together under a single phonological feature value, [+CG].

Finally, the judgment experiments in Chapter 4 confirm that the onset-tone lexical gaps are grammaticalized in Thai. These experiments make two notable contributions.

First, there is evidence that Thai speakers give different judgments depending on whether the same stimuli are treated as English loans or as native Thai words. Three of four onset-tone sequences that are ungrammatical under a native Thai interpretation are found to be grammatical under a loan interpretation. This result is in accordance with findings from many other languages, including Japanese (Ito & Mester 1995, 1999, 2001), where phonological constraints are relativized to separate lexical strata for loan-words and native words. The cross-linguistic tendency for loan strata to be more permissive than native strata is true for Thai as well.

Second, preferences among grammatical onset-tone sequences were discovered. Thai speakers exhibited a preference for low-tone stimuli with [+CG] (unaspirated and voiced) onset consonants over low-tone stimuli with aspirated obstruent onset consonants.

Notably, both of these onset-tone sequences are grammatical in Thai. This preference accords with cross-linguistic observations that there is an affinity between low tone and both [+voice] and [+CG] consonants (Bradshaw 1998; Lee 2008; Tang 2008).

Preferences in judgments between pairs of grammatical stimuli have been reported in a wide range of languages, including English (Coetzee 2008, 2009) and Hebrew (Berent & Shimron 1997). The judgment experiment here adds Thai to this list of languages, lending further evidence that grammar, and specifically markedness, plays a role in language, beyond simply separating the grammatical from the ungrammatical.

The dissertation is structured as follows. Chapter 1 has introduced the topic and main contributions of this dissertation. Chapter 2 introduces the data, providing a detailed corpus and dictionary study of the lexical gaps involving consonant-tone interaction. It closes with evidence from morpho-phonological alternations, of which there is only a

small amount. Chapter 3 presents an acoustic investigation of onset-tone interaction in Thai that establishes a phonetic explanation for the onset-tone interaction. Chapter 4 presents two judgment experiments that confirm the psychological reality of onset-tone sequence restrictions among Thai speakers. Together, Chapters 2, 3, and 4 constitute evidence that onset-tone interaction is synchronically active in the Thai grammar, and not merely a historical relic. Chapter 5 presents an Optimality-theoretic account of consonant-tone interaction, taking Morén & Zsiga's (2006) account as a starting point. In addition, a task-specific weighted-constraint model is offered to explain some of the more subtle findings in the judgment experiment that cannot be explained by a categorical grammar. Chapter 6 is the conclusion.

Chapter 2 – Consonant – Tone Interaction in Thai: An Overview of the Facts

2.1 Introduction

This chapter offers a detailed study of an empirical generalization where certain consonant-tone combinations are ungrammatical in Thai. The primary evidence is based on a lexical gap. A quantitative look at the nature and extent of this gap reveals that it is more complex than what has been reported. Three particular aspects of the quantitative study are highlighted. First, while previous literature has mentioned that only high tone is unattested following unaspirated and voiced stop onsets (Gandour 1974a, 1974b; Tumtavitikul 1992, 1993; Morén & Zsiga 2006; Lee 2008), rising tone is similarly sparsely attested. Second, loans and onomatopoeia appear to constitute exceptions to the restriction of high tone following unaspirated and voiced stop onsets.¹ Third, it is discovered that [h] differs from unaspirated and voiced stops in that it can occur with high and falling tone in checked syllables, a fact that differs from Ruangjaroon's (2006) description. Fourth, there are a fairly large number of exceptional native Thai words that violate the onset – high tone restrictions. On the other hand, the restrictions where mid and rising tone are unattested in syllables with obstruent codas have almost no exceptions at all. This contrast has not been observed before. These observations have a potentially large impact on any phonological account of consonant-tone interaction in Thai. Likewise, since the generalization differs depending on whether a word is native Thai or a loan word, an approach to Thai phonology that is sensitive to different lexical strata is appropriate. Ito & Mester (1995, 1999, 2001) note similar stratified phonologies in Japanese, Jamaican Creole, and German; the findings of this chapter thus add Thai to this

¹ While this fact is noted by Ruangjaroon (2006), her phonological account ignores these exceptions.

list. In addition to lexical frequency, evidence from morpho-phonological alternations is presented, suggesting that consonant-tone lexical gaps are actually encoded in the Thai grammar.

The chapter is organized as follows. Section 2.2 summarizes the empirical generalization as it has been stated in the literature. Section 2.3 offers a detailed quantitative study of the consonant-tone lexical gaps in Thai, suggesting the facts are more complex than they are reported to be. Section 2.4 follows with a presentation of morpho-phonological alternations to assess whether or not the consonant-tone lexical gaps are part of Thai speakers' grammars. Section 2.5 is the conclusion.

2.2 Consonant-Tone Interaction: The Empirical Generalization

Thai has five contrastive tones: High, mid, low, rising, and falling (Abramson 1962, 1975, 1978; Gandour 1981, 1983). Of these, only mid is phonetically level; high tone actually rises from mid to high and low tone actually falls from mid to low (Morén & Zsiga 2006:131-133, fig. 4 & 5). There are twenty-one consonants that can occur in onset position as shown in Table 1 below; however only unaspirated stops, nasals and glides can occur in coda position (shown in bold in Table 1). Labial and alveolar stops have a three-way contrast between voiceless aspirated, voiceless unaspirated and voiced stops, while palatal affricates and velar stops have a two-way contrast between voiceless aspirated and voiceless unaspirated versions.

Onset clusters are attested with a stop (but not an affricate) as the first member and one of [r], [l] or [w] as the second member. Not all possible combinations are attested however: The velar stops can occur in clusters with all three sonorants. Voiceless bilabial

stops [p^h] and [p] can occur in clusters preceding [r] and [l], but not [w]. The only attested cluster involving alveolar stops is [tr]. The voiced stops [b] and [d] do not occur in clusters except in loan words.

Table 1
Consonant Inventory of Thai

	Labial	Alveolar	Palatal	Velar	Glottal
Stop	p ^h p b	t ^h t d	t̪c ^h t̪c	k ^h k	ʔ
Nasal	m	n		ŋ	
Trill		r			
Fricative	f	s			h
Glide	w		j		
Lateral Approximant		l			

Turning now to the focus of this dissertation, consonant-tone interaction, not all possible combinations of onset and tone are claimed to be possible within the same syllable, as shown in Table 2 below (Ruangjaroon 2006). The exact nature of the reported restriction seen in Thai depends on which of two classes the syllable belongs to; so-called “unchecked” syllables refer to those with no coda or with a sonorant coda (including CV:, CV:N and CVN, where N stands for any sonorant coda, here and elsewhere). So-called “checked” syllables refer to those with an obstruent coda (including CV:T and CVT, where T stands for any unaspirated obstruent). High tone does not occur in unchecked syllables with voiced stop onsets or with voiceless unaspirated stop onsets (Gandour 1974a; Tumtavitikul 1992, 1993; Morén & Zsiga, 2006; Ruangjaroon 2006; Lee 2008). The affricate [t̪c] patterns with the unaspirated stops, and so the restriction is more correctly viewed as one involving [–continuant] segments, assuming affricates are [–continuant], following Jakobson et al. (1952). The onset-tone restrictions apply with

onset clusters, based on the first member of the cluster: If it is a voiceless unaspirated stop, then high tone is unattested immediately following it. Ruangjaroon (2006) notes additionally that high tone is unattested in unchecked syllables with ?² or h in onset position. Elsewhere, the full five-way tonal contrast is seen in unchecked syllables; this includes syllables with sonorant onsets, fricative onsets, aspirated stop and aspirated affricate onsets.

According to Ruangjaroon (2006), in checked syllables, tonal contrasts are restricted to a greater degree. Only low tone occurs in checked syllables with voiced stop onsets, voiceless unaspirated onsets or [h]. In checked syllables with all other onsets, a two-way tonal contrast is seen. If the syllable contains a long vowel, falling and low tone are attested; if the syllable contains a short vowel, high and low tone are attested. This distribution of consonant-tone combinations is summarized in Table 2 below.

Table 2
Consonant-Tone Restrictions in Thai – Ruangjaroon, 2006³

	Onset	Mid Tone	Low Tone	Falling Tone	High Tone	Rising Tone
Unchecked	C _{else}	Attested	Attested	Attested	Attested	Attested
	h	Attested	Attested	Attested	Unattested	Attested
	T	Attested	Attested	Attested	Unattested	Attested
	D	Attested	Attested	Attested	Unattested	Attested
Checked	C _{else} & long V	Unattested	Attested	Attested	Unattested	Unattested
	C _{else} & short V	Unattested	Attested	Unattested	Attested	Unattested
	h	Unattested	Attested	Unattested	Unattested	Unattested
	T	Unattested	Attested	Unattested	Unattested	Unattested
	D	Unattested	Attested	Unattested	Unattested	Unattested

² [ʔ] is just another voiceless unaspirated obstruent, and is treated as such here and elsewhere.

³ Here and throughout, “T” refers to any voiceless unaspirated stop or affricate (notably all obstruent codas are voiceless unaspirated stops due to neutralization in codas). “D” refers to any voiced stop. “h” refers to itself. “C_{else}” refers to all other consonants other than these. “N” refers to the class of sonorant consonants.

The status of ʔ in Thai warrants some discussion. Abramson (1962) differs from Ruangjaroon (2006) in his treatment of ʔ-initial words. While Abramson assumes these syllables are all onsetless, Ruangjaroon assumes the presence of a ʔ onset. There is both phonological and phonetic evidence that suggest that a ʔ onset is present in these syllables on the surface: First, high tone does not occur in these syllables, as is the case for syllables with unaspirated stop onsets, a class to which ʔ belongs, suggesting that a ʔ is present. Second, there is a sharp release burst at the onset of these syllables, as illustrated by the spectrogram in Figure 1 below, and there is a pitch-raising effect seen in the beginning of a following vowel (discussed in detail in Chapter 3). These facts together suggest the presence of a ʔ onset that patterns with the voiceless unaspirated stops.

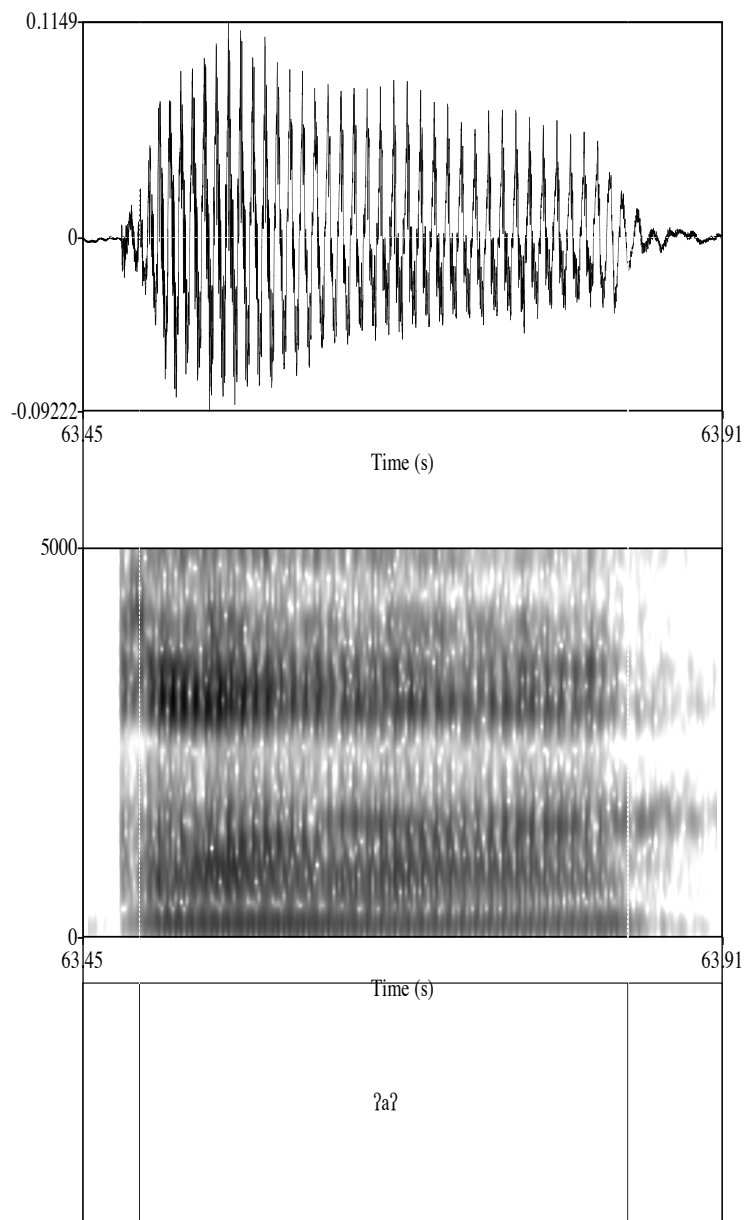


Fig. 1 – Glottal Stop Onset

ʔ can also occur as a coda in Thai, but only with short vowels. CVʔ syllables were treated as open CV syllables by Abramson (1962) even though most accounts note the presence of a glottal stop coda in these syllables (Gandour 1974a; Morén & Zsiga 2006). Morén & Zsiga (2006) argue that there is a glottal stop, but that it is epenthetic, filling a

requirement for Thai syllables to be bimoraic. They note that its distribution is predictable, and that its interaction with weight and tone only depends on markedness considerations. Notably, $C_{\text{else}}V?$ syllables can occur with low or high tone, just like $C_{\text{else}}VT$ syllables. It is assumed that $?$ is present on the surface here, making no assumptions about its underlying status.

This section has presented the empirical facts for Thai consonant-tone interaction as reported by Ruangjaroon (2006). However, beyond the representational issues discussed here, there is the issue of the empirical facts that the accounts are attempting to explain in the first place: They assume a clear distinction in grammaticality among certain consonant-tone combinations. The remainder of this chapter critically assesses this assumption on two fronts. Section 2.3 presents a detailed investigation of the extent of the lexical gaps reported by Ruangjaroon. Section 2.4, meanwhile, investigates evidence involving morpho-phonological alternations in Thai. The evidence is consistent with many of the generalizations reported above; however there are also many observations that cast some doubt on the accuracy of the generalizations, particularly in the extent and nature of the lexical gaps involving onset-tone combinations. The main focus of this dissertation is to try to piece together a clearer picture of the empirical generalizations for the onset-tone restrictions via a production study (Chapter 3) and a perceptual experimental study (Chapter 4). Once the evidence is clarified, this will allow the construction of a correct phonological account of consonant-tone interaction in Thai (Chapter 5).

2.3 Evidence from Lexical Frequency

The previous sections offered a description of the empirical facts of consonant-tone interaction in Thai. However, the next two sections assess the evidence that these accounts are based on, which turns out to be more complex than it is reported to be. Ruangjaroon (2006:39-66) listed a subset of the monosyllabic words in Thai to show that there are lexical gaps corresponding to the ungrammatical consonant-tone combinations. This section offers a quantitative approach using an online Thai dictionary (Slayden 2013) and a written Thai corpus (Kasuriya et al. 2003). This quantitative approach improves upon previous characterizations in three ways: First, it is discovered that rising tone, in addition to high tone, appears to be under-represented in unchecked syllables with voiceless unaspirated and voiced onsets. Second, a more detailed treatment of type frequencies in different lexical classes is offered, confirming Ruangjaroon's observation that loans and onomatopoeia are exceptional in that some of the consonant-tone restrictions are relaxed in these classes. Third, a finer distinction is made between consonant-tone combinations that are completely unattested, containing almost no lexical exceptions, and those that are *under-represented*, containing a relatively larger number of lexical exceptions. Namely, while the restrictions involving mid and rising tone have few, if any exceptions, high and falling tone restrictions have a relatively larger number of lexical exceptions. In order to quantify the categories "attested", "under-represented" and "unattested", the following definitions are offered.⁴

⁴ The exact percentages used in this definition are arbitrary.

- (2a) **Unattested:** Tone X is *unattested* in some syllable type, Y, if the number of words with tone X in syllable type Y is less than 1% of the total number of words with syllable type Y.
- (2b) **Under-represented:** Tone X is *under-represented* in some syllable type, Y, if the number of words with tone X in syllable type Y is greater than 1% but less than 10% of the total number of words with syllable type Y.
- (2c) **Attested:** Tone X is *attested* in some syllable type, Y, if the number of words with tone X in syllable type Y is greater than or equal to 10% of the total number of words with syllable type Y.

A separate question, addressed in Chapter 4, is whether these more subtle aspects of the Thai lexicon are encoded in a speaker's grammar, or whether speakers make more sweeping generalizations.

Lexical type frequencies were calculated using an online Thai dictionary (Slayden 2013). This dictionary is fully supervised by a three-person editing team, at least one of whom has linguistic training. One of the editors is a native Thai speaker; the remaining two editors are fluent Thai speakers. All entries are cross-checked with at least two independent sources. Web-forms are available for the public to report errors; however, these are checked for correctness prior to being implemented in the dictionary. Lexical frequencies reported here are for the total number of monosyllables that are attested words of Thai. An excel spreadsheet was populated with all $32,110^5$ possible

⁵ There are 21 possible simple onsets and 17 possible complex onsets, for a total of 38 possible onsets. There are 9 monophthongal vowels and 3 diphthongs, for a total of 12 distinct vowel qualities. There are 5 tones, 2 vowel lengths and 9 possible codas: $38 \text{ onsets} * 12 \text{ vowels} * 5 \text{ tones} * 2 \text{ vowel lengths} * 9 \text{ codas} =$

monosyllables that can be built with the Thai inventory of segments, tone and vowel length. The spreadsheet included a field encoding whether the monosyllable was an attested word in Thai or not, to facilitate frequency calculations. The online dictionary was consulted between February 11 and 14, 2013 in order to fill in the word-status field for each monosyllable.

In addition to the dictionary, type frequencies were calculated from the ORCHID Thai text corpus (Kasuriya et al. 2003). The ORCHID corpus is a text corpus taken from Thai technical and scientific journals; it is not necessarily representative of common speech then. The corpus contains approximately 400,000 words all in Thai orthography. It was translated into IPA via a Ruby script, in order to allow lexical analysis based on phonemic distinctions. Thai orthography correlates closely to phonetic pronunciation, so that this translation is feasible for monosyllabic words. In multisyllabic words that contain VCCV sequences, it is not generally predictable whether the first C is a coda or part of an onset cluster. By limiting the study to monosyllables, this ambiguity is not an issue.

Since the interest here is in checking the extent of a phonological gap, the primary concern is whether a given phonological form is attested or not. As a result, only a single monosyllable is counted when there are a number of synonyms of a given phonological shape, rather than one for each distinct lexical item. For example, the noun “shack” and the verb “to thrash” are both pronounced as [p^háʔ], but this is counted only once.

Monosyllables with onset clusters are included as well, with the initial member of the cluster determining the syllable-type.

41,040 possible monosyllables. However, glide codas occur with a restricted subset of vowels, resulting in a total of 32,110 total possible monosyllables.

Tables 3 and 4 below list the number of attested monosyllabic words, classified by syllable type and tone in the dictionary search and the corpus, respectively. The shaded cells indicate combinations of syllable-type and tone that are reported as unattested in Thai by Ruangjaroon (2006). For a given cell in the tables below, two values are listed: On the left, the raw type frequency from the search is listed; on the right, the proportion among all words of syllable type Y that have tone X is reported. To give an example, for the top-left cell in Table 3, there are 628 unchecked syllable words with a C_{else} onset and with mid tone ÷ 1840 total C_{else} unchecked syllable words, which equals 34.1%. This percentage is offered as an indicator of the extent of a lexical gap, and is superior to the raw type frequencies since the syllable classes are not always of equal size.

Table 3
Lexical Type Frequency for Thai Monosyllabic Words in the Dictionary

	Onset	Mid Tone		Low Tone		Falling Tone		High Tone		Rising Tone		Total
Unchecked	C _{else}	628	34.1%	184	10.0%	400	21.7%	278	15.1%	350	19.0%	1840
	h	21	17.1%	19	15.4%	29	23.6%	11	8.9%	43	35.0%	123
	T	292	43.5%	142	21.2%	156	23.2%	29	4.3%	52	7.7%	671
	D	79	42.7%	40	21.6%	51	27.6%	7	3.8%	8	4.3%	185
Checked	C _{else} & Long V	0	0.0%	131	33.8%	233	60.1%	24	6.2%	0	0.0%	388
	C _{else} & Short V	2	0.5%	131	31.9%	16	3.9%	261	63.5%	1	0.2%	411
	h & Long V	0	0.0%	16	61.5%	9	34.6%	1	3.8%	0	0.0%	26
	h & Short V	0	0.0%	16	53.3%	1	3.3%	13	43.3%	0	0.0%	30
	T	0	0.0%	247	74.6%	10	3.0%	71	21.5%	3	0.9%	331
	D	0	0.0%	78	80.4%	2	2.1%	17	17.5%	0	0.0%	97

Table 4
Lexical Type Frequency for Thai Monosyllabic Words in the ORCHID Corpus

	Onset	Mid Tone		Low Tone		Falling Tone		High Tone		Rising Tone		Total
Unchecked	C _{else}	176	35.3%	43	8.6%	114	22.9%	77	15.5%	88	17.7%	498
	h	2	8.0%	3	12.0%	7	28.0%	1	4.0%	12	48.0%	25
	T	84	54.5%	34	22.1%	32	20.8%	1	0.6%	3	1.9%	154
	D	26	56.5%	13	28.3%	7	15.2%	0	0.0%	0	0.0%	46
Checked	C _{else} & Long V	0	0.0%	32	29.6%	72	66.7%	4	3.7%	0	0.0%	108
	C _{else} & Short V	0	0.0%	41	34.2%	0	0.0%	79	65.8%	0	0.0%	120
	h & Long V	0	0.0%	3	60.0%	2	40.0%	0	0.0%	0	0.0%	5
	h & Short V	0	0.0%	2	100.0%	0	0.0%	0	0.0%	0	0.0%	2
	T	0	0.0%	70	93.3%	1	1.3%	4	5.3%	0	0.0%	75
	D	0	0.0%	26	100.0%	0	0.0%	0	0.0%	0	0.0%	26

Tables 3 and 4 highlight two important findings. First, rising tone is relatively under-represented in unchecked syllables with unaspirated (T) and voiced (D) onsets. While there are 52 “unchecked-T” words with rising tone in the dictionary, this accounts for only 7.7% of the “unchecked-T” words in Thai. This percentage is much lower than other attested combinations, and is more similar to the percentage for high tone in those syllable types. Additionally, there are only 8 “unchecked-D” words with rising tone, accounting for only 4.3% of all “unchecked-D” words. The corpus frequencies are even lower at 1.9% and 0%, respectively. These results suggest that not only high tone, but also rising tone is restricted in unchecked syllables with voiced and unaspirated onsets.

Second, there are a large number of words that violate the various high-tone (and to a lesser extent, falling tone) restrictions.⁶ In the dictionary, there are 148 Thai words that violate various high-tone restrictions and 28 that violate falling-tone restrictions. However, there are only 2 that violate mid-tone restrictions, and only 4 that violate rising-tone restrictions in the dictionary, and no exceptions to the mid and rising tone

⁶ All native Thai words that violate the various consonant-tone restrictions are listed in Appendix A.

restrictions in the corpus. Therefore, the extent of a given lexical gap varies depending on the tone involved in the gap.

Third, the lexical statistics for [h] suggest a different distribution than the one suggested by Ruangjaroon (2006). In unchecked syllables, there are significantly fewer h-initial words with high tone compared to the other four tones. This latter result is in agreement with Ruangjaroon (2006): high tone is restricted following [h] onsets. Finally, the rising-tone restriction that applies to unaspirated and voiced obstruent-initial words, doesn't apply to h-initial words. In fact, rising tone is the most common tone following an [h] onset in unchecked syllables. In checked syllables, [h] appears to pattern with C_{else}, rather than T or D. In words with a long vowel, there are 9 falling-tone words, but only a single high-tone word. In words with a short vowel, there are no falling-tone words, but 8 high-tone words. These facts suggest that the only behavior separating [h] from other fricatives is a gap with high tone in unchecked syllables. Otherwise, it behaves like any other fricative.

Prior to examining the lexical distribution shown in Table 2 any further, it is important to note that loan words and onomatopoeia do not adhere to the consonant-tone restrictions involving high tone (Ruangjaroon 2006). As a result, the distribution in Tables 3 and 4 may not accurately portray some of the more subtle distributional facts concerning consonant-tone interaction. Fortunately, entries in Slayden's (2013) dictionary include information on onomatopoeic and loan status. Table 5 includes counts for monosyllables that are listed as English loans (shading reflects lexical gaps reported in previous accounts).⁷ Likewise, Table 6 lists counts for onomatopoeia. Due to the

⁷ English loans far outnumber loans from other languages in Slayden's dictionary. Chinese, Sanskrit and Pali loans are fairly common as well, but are not included here.

relatively small number of onomatopoeia, loan words are the focus of the discussion below. Nevertheless, it is still apparent that high tone is indeed attested in onomatopoeia in checked syllables, while it is not reported to occur in these syllable types in native Thai words.

Table 5
Lexical Type Frequency for Monosyllabic English Loan Words

	Onset	Mid Tone		Low Tone		Falling Tone		High Tone		Rising Tone		Total
Unchecked	C _{else}	151	93.2%	1	0.6%	3	1.9%	7	4.3%	0	0.0%	162
	h	11	91.7%	0	0.0%	0	0.0%	1	8.3%	0	0.0%	12
	T	56	87.5%	0	0.0%	2	3.1%	6	9.4%	0	0.0%	64
	D	33	82.5%	0	0.0%	3	7.5%	3	7.5%	1	2.5%	40
Checked	C _{else} & Long V	0	0.0%	5	6.3%	58	73.4%	16	20.3%	0	0.0%	79
	C _{else} & Short V	2	2.9%	3	4.4%	0	0.0%	63	92.6%	0	0.0%	68
	h & Long V	0	0.0%	0	0.0%	4	100.0%	0	0.0%	0	0.0%	4
	h & Short V	0	0.0%	0	0.0%	0	0.0%	3	100.0%	0	0.0%	3
	T	0	0.0%	18	48.6%	2	5.4%	17	46.0%	0	0.0%	37
	D	0	0.0%	21	67.7%	1	3.2%	9	29.0%	0	0.0%	31

Table 6
Lexical Type Frequency for Thai Monosyllabic Onomatopoeia

	Onset	Mid Tone		Low Tone		Falling Tone		High Tone		Rising Tone		Total
Unchecked	C _{else}	5	22.7%	4	18.2%	5	22.7%	3	13.6%	5	22.7%	22
	h	3	30.0%	1	10.0%	3	30.0%	2	20.0%	1	10.0%	10
	T	4	25.0%	1	6.2%	4	25.0%	1	6.2%	6	37.5%	16
	D	0	0.0%	0	0.0%	1	50.0%	0	0.0%	1	50.0%	2
Checked	C _{else} & Long V	0	0.0%	3	50.0%	1	16.7%	2	33.3%	0	0.0%	6
	C _{else} & Short V	0	0.0%	5	55.6%	1	11.1%	3	33.3%	0	0.0%	9
	h & Long V	0	0.0%	0	0.0%	1	100.0%	0	0.0%	0	0.0%	1
	h & Short V	0	0.0%	2	100.0%	0	0.0%	0	0.0%	0	0.0%	2
	T	0	0.0%	12	42.9%	3	10.7%	12	42.9%	1	3.6%	28
	D	0	0.0%	6	50.0%	0	0.0%	6	50.0%	0	0.0%	12

The proportions of words that violate high-tone restrictions are larger in loans and onomatopoeia than they are generally in Thai. This indicates that a large proportion of the high-tone exceptions in Table 3 are from English loans and onomatopoeia. On the other

hand, the restrictions on mid, falling and rising tone are obeyed in loans, with almost no exceptions. There are 54 English loan words that violate various high-tone restrictions, but only 2 that violate mid-tone restrictions, only 7 that violate falling-tone restrictions, and none that violate rising-tone restrictions. The checked syllable restrictions on mid, falling, and rising tone hold in loan words then. However the data in Table 5 imply that there are *no* restrictions on high tone in English loan words, as high tone is attested in every syllable class. While high tone is under-represented in unchecked syllable loan words, it is still the second most frequently attested tone. This is true even for voiced and unaspirated onsets.

There is also a more subtle aspect to the loan word data in Table 5. It is apparent that for each syllable class, there is a tendency to have a dominant “default” tone. In unchecked syllables, mid tone is overwhelmingly dominant (cf. Kenstowicz & Suchato 2006, who made the same observation for English loan words; these authors did not inspect loan distribution for onset-tone restrictions, however). In checked syllables meanwhile, falling tone is dominant in $C_{\text{else}}V:T$ words and high tone is dominant in $C_{\text{else}}VT$ words. The picture is less clear however when looking at checked syllables with voiced and unaspirated onsets. In DVT syllables, low tone is slightly more prevalent but in TVT syllables, low and high tone are almost evenly split. The predominance of mid tone in loan words with unchecked syllables overshadows the fact that loan words with high tone actually outnumber all other tones, even with voiced and unaspirated onsets. Thus, while the total frequency of high tone in “unchecked-D” and “unchecked-T” words is low, it is relatively high compared to low, rising and falling tone. This fact is unique to English loan words.

Since loan words and onomatopoeia are exceptional, the lexical statistics for the dictionary are repeated with loans and onomatopoeia filtered out in Table 7 below. This illustrates the lexical frequency statistics in *native* Thai words. In addition to onomatopoeia, words that are tagged in the dictionary as “colloquial”, “archaic”, “formal”, or “poetic” are also removed⁸ so as to exclude any other potential lexical stratum effects.

Table 7
Lexical Type Frequency for Monosyllabic Native Thai Words

	Onset	Mid Tone		Low Tone		Falling Tone		High Tone		Rising Tone		Total
Unchecked	C _{else}	490	30.9%	167	10.5%	368	23.2%	242	15.2%	321	20.2%	1588
	h	3	3.8%	15	18.8%	23	28.8%	2	2.0%	37	46.2%	80
	T	242	43.5%	134	24.1%	138	24.8%	13	2.3%	29	5.2%	556
	D	53	38.7%	36	26.3%	43	31.4%	0	0.0%	5	3.6%	137
Checked	C _{else} & Long V	0	0.0%	121	39.8%	178	58.6%	5	1.6%	0	0.0%	304
	C _{else} & Short V	0	0.0%	115	37.7%	10	3.3%	179	58.7%	1	0.3%	305
	h & Long V	0	0.0%	14	82.4%	3	17.6%	0	0.0%	0	0.0%	17
	h & Short V	0	0.0%	12	80.0%	0	0.0%	3	20.0%	0	0.0%	15
	T	0	0.0%	226	84.3%	4	1.5%	37	13.8%	1	0.4%	268
	D	0	0.0%	57	91.9%	1	1.6%	4	6.5%	0	0.0%	62

There are two notable observations that are apparent in Table 7. First, [h] is under-represented in the native Thai stratum preceding mid tone, in addition to high tone. This observation concerning mid tone has not been made before in previous accounts. Second, while the total number of high-tone exceptions is reduced to 64, there are still significantly more exceptions than we see with other tones.⁹ High tone is even fully attested (> 10%) in TV:T and TTV syllables, contrary to what is reported. Likewise,

⁸ Words listed as “loan”, “onomatopoeia”, “colloquial”, “archaic”, “formal” or “poetic” but that also had a listing without one of these tags were retained, since they have at least one native use.

⁹ Notably, 50 of these high-tone exceptions occur following unaspirated stops; there are only 4 native Thai words where high tone follows a voiced stop (none in unchecked syllables). While I treat voiced and unaspirated stops together as under-represented, it is possible that there may be a grammatical distinction between them based on these different type frequencies.

while there are some words with rising tone following voiced or unaspirated onsets in unchecked syllables in the native Thai lexicon, this combination is significantly under-represented. The mid and rising tone restrictions have zero and two exceptions, respectively. Whatever the grammatical status of the various high-tone restrictions is, there is a definite contrast with the mid and rising tone restrictions in the lexical gaps. This contrast is described by employing the terms “under-represented” and “unattested”, as defined above in (2). Table 8 summarizes the conclusions based on lexical frequency statistics discussed above.

Table 8
Summary of Consonant-Tone Restrictions in Thai by Lexical Stratum

	Consonant-Tone Restriction		Native Thai Words	English Loan Words
	Onset	Tone		
Unchecked	h	High	Under-represented	Under-represented
	h	Mid	Under-represented	Attested
	T	High	Under-represented	Under-represented
	D	High	Unattested	Under-represented
	T	Rising	Under-represented	Unattested ¹⁰
	D	Rising	Under-represented ¹¹	Under-represented
Checked	All	Mid & Rising	Unattested	Unattested
	D	High	Under-represented	Attested
	T	High	Attested	Attested
	D	Falling	Under-represented	Under-represented
	T	Falling	Under-represented	Under-represented

An important observation concerns a difference between the status of lexical gaps among unchecked syllables with high tone. While in native words, the *unaspirated-high* and *voiced-high* combinations are significantly under-represented in comparison to mid, falling and low tones, in loan words, they are only underattested in comparison to mid

¹⁰ Rising tone is unattested in all English loan words. This is not particular to unchecked syllables then.

¹¹ There is a single example with a voiced stop onset, resulting in the “under-represented” status with voiced onsets.

tone. In fact, in English loans, high tone is more prevalent than mid, falling and low tones in unchecked syllables with unaspirated and voiced onsets. This indicates that apart from an apparent bias in borrowing English loans in unchecked syllables as mid tone, high tone is acceptable.

Assuming for now that the Thai grammar is based on lexical type frequency¹², we expect that “attested” combinations should correspond to grammatical combinations, and that “unattested” combinations should correspond to ungrammatical combinations. It is less clear how “under-represented” combinations should be treated. One possibility is that gradient grammatical distinctions exist, and that speakers will judge the under-represented combinations as having an intermediate grammaticality – they would be better than unattested combinations, but worse than attested combinations. Studies on gradient grammaticality judgments date back to Greenberg & Jenkins (1964), who first discovered gradient preferences in English speakers. Coetzee (2008) provides evidence on the OCP-Place in English that shows that speakers have preferences among ungrammatical forms. Kirby & Yu (2007) found that onset-tone gaps in Cantonese were judged more grammatical than accidental gaps but that words containing a banned coronal-back vowel sequence were dispreferred to accidental gaps. However, they also found that nonwords that contained a banned OCP-labial sequence were judged as no different from accidental gaps. Therefore, while gradient grammaticality is a possibility

¹² There is a large body of research that has shown that lexical frequency makes a unique contribution to judgments apart from grammaticality (Newman et al., 1997; Coleman & Pierrehumbert, 1997; Vitevitch & Luce, 1998, 1999; Bailey & Hahn, 2001; Frisch et al., 2000, Shademan, 2007). However, here the possibility is entertained, merely for the sake of argument, that the grammar itself incorporates lexical statistics to some extent. In Thai, if the only evidence a language-learner encounters is in the form of lexical gaps, then any grammatical generalization thus formed has at its root lexical frequency statistics of some kind.

for the “under-represented” combinations, it is not a given. The question of the relative grammaticality is addressed via two judgment experiments in Chapter 4.

A second possibility is that Thai speakers have begun to generalize high and falling tone as being possible in *all* checked syllables in their grammar, regardless of onset or vowel length. The extent of this generalization may even extend across the board, so that high tone is grammatical in all syllable types. This hypothesis is likely if we view the loan word data as indicative of the state of speakers’ actual phonological grammars; the relatively small number of lexical items with high tone in “unchecked-T” and “unchecked-D” syllables may then be an accidental gap with a diachronic explanation. Newly coined words, such as most English loan words for example, do not adhere to the consonant-tone restrictions because these restrictions are no longer active in modern Thai, under this hypothesis. In this case, we would expect to find “under-represented” and “attested” combinations as equally grammatical, since the under-represented combinations only reflect diachronic, and not synchronic processes.

This is in stark contrast to a theory where Thai speakers separate different classes of words, like loans and onomatopoeia, treating them differently with respect to consonant-tone interaction. This kind of lexical stratification has been attested in Japanese (Ito & Mester 1995, 1999), English (Pierrehumbert 2006), Jamaican Creole and German (Ito & Mester 2001). In Yorùbá, English loanwords do not adhere to usual vowel harmony restrictions that apply to words. Words in Yorùbá do not contain adjacent vowels whose feature value for [advanced tongue root] ([ATR]) are different (Archangeli & Pulleyblank 1989; Perkins 2005). For example, [ekpɔ] ‘oil’ has two [+ATR] vowels and [ɔbɛ̀] ‘soup’ has two [–ATR] vowels. Yorùbá does not allow words in the native lexicon like *[ekpɔ]

or *[ɔ̀bè] with one [+ATR] vowel and one [–ATR] vowel. Exceptions are seen however in English borrowings as shown in (3) below (Bamgboṣe 1967:273; Archangeli & Pulleyblank 1989:182-183):

(3) English loanword exceptions in Yorùbá vowel harmony

- | | | |
|-----|---------|-------------|
| (a) | [fɔ̀tò] | ‘photo’ |
| (b) | [télò] | ‘tailor’ |
| (c) | [bébà] | ‘paper’ |
| (d) | [mótò] | ‘motor car’ |

Archangeli & Pulleyblank analyze the [ATR] feature as a root-level feature in native Yorùbá words, but as a segment-level feature in loans. However, another possibility, the one explored here, is that loans in both Yorùbá and Thai occupy a separate lexical stratum that the phonology has access to.

Ito & Mester (2001) argue that lexical stratifications of these types are best accounted for by stratum-specific faithfulness, which interleaves among a fixed (language-specific) markedness constraint hierarchy. Under this hypothesis, the Yorùbá and Thai facts may be accounted for via a separation of the relevant faithfulness constraints, specific to loan and native lexical items. In Thai, the onset-tone restrictions involving high tone apply in native words but not in loan words. However, the rising tone restrictions apply in both native and loan words. This would imply that in Thai, faithfulness to the loan stratum must dominate a markedness constraint that is violated by sequences of voiced or

unaspirated obstruents and high tone. However, faithfulness to the native stratum is outranked by this markedness constraint so that these sequences do not occur in the native lexicon. The following ranking scheme illustrates this situation in Thai:

(4) Ranking Scheme in Thai with Lexical Stratification of Loans

* Voiced Stop – R Tone >> Faith (Loan) >> * Voiced Stop – H Tone >> Faith (Native)

If a word is perceived as native Thai, speakers would judge the voiced – high sequences as ungrammatical, since the markedness constraint *Voiced Stop – H Tone outranks Faith (Native). However, if the word is perceived as a loan word, voiced – high sequences are acceptable because Faith (Loan) outranks the markedness constraint, *Voiced Stop – H Tone. On the other hand, the markedness constraint involving rising tone outranks both faithfulness constraints, and so voiced – rising sequences are ungrammatical regardless of whether the word is perceived as a loan or native word. In Chapter 4, this prediction is tested via a forced choice experiment where the task instructions are varied in order to elicit loan interpretations in one version and native interpretations in the other.

This section offered a detailed presentation of the lexical distribution of consonant-tone combinations in Thai. Phonological accounts have cited these lexical gaps as the evidence for a phonological process. However, lexical gaps often have diachronic explanations, and indeed there is such evidence for Thai that offers a diachronic explanation for the consonant-tone gaps (Diller 1996; Yip 2002). While this dissertation

does not refute the presence of a diachronic explanation for the gap, it is an independent question to ask whether this gap is also encoded in the synchronic system of Thai speakers – this is one goal of this dissertation. In the process of acquiring a language, learners see only patterns in the data, and not the historical source of those patterns. One source for evidence of a synchronic grammatical restriction is via morpho-phonological alternations. The following section outlines some potential morphological environments where alternations would be expected to occur.

2.4 Evidence From Alternations

In the previous section, we saw that onset-tone combinations involving voiced or unaspirated onsets with high and rising tone in unchecked syllables are under-represented in the Thai lexicon. This section explores evidence from alternations involving the high-tone restriction in unchecked syllables. Ruangjaroon (2006) presents two cases where we would expect a morpho-phonological alternation to occur, involving onset-high tone interaction. The first case, summarized in Section 2.4.1, involves reduplication of an H-tone prefix; the second case, summarized in Section 2.4.2, involves a Thai word-game that swaps syllable rimes in two members of a compound word. In intensifying reduplication, outputs exist with voiced or unaspirated onsets preceding high tone; however in the Thai word game, there is active avoidance of voiced or unaspirated onsets preceding high tone. This section analyzes and assesses the evidence for the grammaticality of the onset-tone restrictions involving high tone in unchecked syllables.

2.4.1 Intensifying Reduplication

Ruangjaroon (2006) investigates reduplication as a potential site where one would expect to see an alternation occur. This reduplication involves copying the entire base as an intensifying prefix, but with a fixed high tone on the prefix, as shown in (5) below (Ruangjaroon 2006:32, ex. 42).

(5) Intensifying Reduplication in Thai


- | | | |
|----|--------------------------|-----------------------------|
| a. | bùua: | “bored” |
| | búua:bùua: ¹³ | “very bored” |
| b. | dòk | “productive, fruitful” |
| | dókdòk | “very productive, fruitful” |
| c. | tɛ̀i̯w | “small” |
| | tɛ́i̯wcì̯w | “very small” |
| d. | hǒm | “good smelling” |
| | hómhǒm | “very good smelling” |

Recall that voiced onsets do not precede high tone in both checked and unchecked syllables, as discussed above. However, even when a voiced stop is in the onset, the high tone on the reduplicant still surfaces. Ruangjaroon analyzes this by ranking a faithfulness constraint protecting the H tone in the reduplicant (MAX_{O-R} H) above an onset-tone restricting markedness constraint. The general constraint MAX H is ranked below the

¹³ Ruangjaroon transcribes this diphthong as [i̯a], whereas it is transcribed here as [ua:]. This is the same vowel and no claim is made on whether it is truly a back vowel or a central vowel, phonetically

markedness constraint, accounting for the fact that outside of the reduplicant, the voiced stop-high tone sequence is ungrammatical. This is summarized in tableau (6) below (a simplified version of Ruangjaroon 2006:33 ex. 43).

(6)

/RED, H/ + /buà:/	MAX _{O-R} H	*Voiced-H Tone ¹⁴	MAX H
 a. buàa:buàa:		*	
b. buàa:buàa:	*!		*

There is another possible explanation, however. Perhaps there is no such onset-tone restricting markedness constraint (like *Voiced-H Tone) in the synchronic phonology, and the lexical gap explored in Section 2.3 is simply an accidental gap. The fact that many English loans exist that violate the voiced stop-high tone restriction is consistent with this. The intensifying reduplication data would thus be unsurprising as well in this view. This latter hypothesis predicts that Thai speakers should find no difference in grammaticality between nonce words violating the onset-tone restriction and nonce words that are otherwise grammatically well-formed. The word-game data presented in the following subsection suggest that this is not the case however.

2.4.2 *A Thai Word Game*

While the intensifying reduplication data in Section 2.4.1 cast doubt on the grammatical status of the consonant-tone restrictions, there is also some evidence that Thai speakers avoid forms where high tone comes together with a voiced or unaspirated

¹⁴ This is a simplified version of Ruangjaroon's conjunctive constraint *[-SG]∞[v̌] & *[v̌]∞[-SG]. While not identical, it serves the same purpose in this example, which is to act as a markedness constraint against the relevant violating consonant-tone sequence.

stop in a Thai word game. This word game involves compounds formed by two monosyllabic roots. The word-game switches the two rimes. The tone can optionally switch along with the rime (option 2 in (7) and (8) below) or not (option 1 in (7) and (8) below). The following examples are from Ruangjaroon (2006:11, ex. 18 & 19).

(7) Optional Tone Switching in a Thai Word Game

- | | | |
|----|--------------------------|---|
| a. | p ^h ǒm | “hair” |
| | sân | “short” |
| | p ^h ǒmsân | “short hair” |
| | p ^h ǎnsôm | word-game option 1 for “short hair” |
| | p ^h ânsǒm | word-game option 2 for “short hair” |
| b. | k ^h àp | “to drive” |
| | rót | “car” |
| | k ^h àprót | “to drive a car” |
| | k ^h òtráp | word-game option 1 for “to drive a car” |
| | k ^h ótráp | word-game option 2 for “to drive a car” |
| c. | t ^h ǎ:n | “to pull out” |
| | t̂caj | “heart” |
| | t ^h ǎ:n̂t̂caj | “to sigh” |
| | t ^h ǎjt̂cɔ:n | word-game option 1 for “to sigh” |

t^hajtēɔ̃:n word-game option 2 for “to sigh”¹⁵

However, whenever such a switch would result in a high tone following a voiced or unaspirated onset, that form is not allowed (as in 8a-d below).

(8) Evidence for High Tone Restrictions in a Thai Word Game

- a. tē^há:w “morning”
 bà:j “afternoon”
 tē^há:wbà:j “morning and afternoon”
 tē^há:jbà:w word-game option 1 for “morning and afternoon”
 * tē^hà:jbá:w word-game option 2 for “morning and afternoon”
- b. lé:w “already”
 kan “self”
 lé:wkan “what a nuisance”
 lánkɛ:w word-game option 1 for “what a nuisance”
 * lanké:w word-game option 2 for “what a nuisance”

¹⁵ Interestingly, option 2 in (7c) is listed as grammatical despite the fact that it contains an under-represented unaspirated onset-rising tone sequence. This indicates that the high tone restriction is active with unaspirated stop onsets, but that the rising tone restriction is not.

- c. k^híw “eyebrows”
 kòŋ “arched”
 k^híwkòŋ “arched eyebrows”
 k^hóŋkiw word-game option 1 for “arched eyebrows”
 * k^hòŋkiw word-game option 2 for “arched eyebrows”
- d. kê:w “glass”
 rá:w “crack”
 kê:wrá:w “a cracked glass”
 kâ:wré:w word-game option 1 for “a cracked glass”
 * ká:wrê:w word-game option 2 for “a cracked glass”

The word-game offers evidence that there is a grammatical restriction on high tone occurring in unchecked syllables following unaspirated and voiced onsets.

2.4.3 *A Possible Explanation: The Domain of Onset-Tone Restrictions*

While Ruangjaroon’s analysis of intensifier reduplication involves a constraint that specifically refers to the reduplicant, another possibility is that the markedness constraint only exerts its influence inside morphological roots. Perhaps in affixes, for example, the consonant-tone restrictions do not exist. The reduplication data shown above may in fact be a more general fact about the domain of consonant-tone restriction in Thai then: It applies only within the morphological root domain. This hypothesis would explain why

in the word-game, which involves morphological roots, we see the onset-tone restrictions in action, but in the reduplication, we do not. In order to explore this possibility, a dictionary search was conducted, focusing on consonant-tone sequences in monosyllabic affixes and other non-root particles. Slayden (2013) marks entries as prefixes, suffixes and/or particles. The Thai classifiers (essentially prefixes) are marked as particles in the dictionary and make up the largest portion of the bound morphemes in the dictionary. Any entry not marked as a prefix, suffix or particle, is assumed to be a morphological root.¹⁶ Table 9 below summarizes lexical frequencies for non-roots (a) and roots (b).

Table 9
Lexical Frequencies for Roots and Non-Roots in Thai

a. Lexical Type Frequency for Non-Roots in Thai

	Onset	Mid Tone		Low Tone		Falling Tone		High Tone		Rising Tone		Total
Unchecked	C _{else}	95	37.1%	19	7.4%	58	22.7%	31	12.1%	53	20.7%	256
	h	1	7.7%	3	23.1%	4	30.8%	0	0.0%	5	38.5%	13
	T	46	50.0%	10	10.9%	28	30.4%	3	3.3%	5	5.4%	92
	D	9	42.9%	1	4.8%	9	42.9%	1	4.8%	1	4.8%	21
Checked	C _{else} & Long V	0	0.0%	13	34.2%	25	65.8%	0	0.0%	0	0.0%	38
	C _{else} & Short V	0	0.0%	16	26.2%	9	14.8%	35	57.4%	1	1.6%	61
	h & Long V	0	0.0%	2	100.0%	0	0.0%	0	0.0%	0	0.0%	2
	h & Short V	0	0.0%	1	33.3%	1	33.3%	1	33.3%	0	0.0%	3
	T & Long V	0	0.0%	11	73.3%	0	0.0%	4	26.7%	0	0.0%	15
	T & Short V	0	0.0%	19	76.0%	2	8.0%	4	16.0%	0	0.0%	25
	D & Long V	0	0.0%	4	100.0%	0	0.0%	0	0.0%	0	0.0%	4
	D & Short V	0	0.0%	4	100.0%	0	0.0%	0	0.0%	0	0.0%	4

¹⁶ It is possible for a given word to be listed as both a root and a non-root, and indeed this was the case for many dictionary entries. For example, [p^hɛːŋ] is both the pronunciation of a noun meaning “stall” or a numerical classifier prefix for medicines sold in plastic or foil sheets. In cases such as these, the entry was counted in both categories.

b. Lexical Type Frequency for Roots in Thai

	Onset	Mid Tone		Low Tone		Falling Tone		High Tone		Rising Tone		Total
Unchecked	C _{else}	613	33.9%	183	10.1%	395	21.8%	275	15.2%	344	19.0%	1810
	h	19	16.2%	19	16.2%	28	23.9%	10	8.5%	41	35.0%	117
	T	286	43.5%	142	21.6%	152	23.1%	27	4.1%	51	7.8%	658
	D	79	43.4%	40	22.0%	50	27.5%	6	3.3%	7	3.8%	182
Checked	C _{else} & Long V	0	0.0%	128	33.6%	229	60.1%	24	6.3%	0	0.0%	381
	C _{else} & Short V	2	0.5%	126	32.1%	10	2.6%	253	64.5%	1	0.3%	392
	h & Long V	0	0.0%	15	65.2%	8	34.8%	0	0.0%	0	0.0%	23
	h & Short V	0	0.0%	14	56.0%	0	0.0%	11	44.0%	0	0.0%	25
	T & Long V	0	0.0%	124	78.0%	2	1.3%	33	20.8%	0	0.0%	159
	T & Short V	0	0.0%	122	72.4%	6	4.7%	34	21.2%	3	1.8%	165
	D & Long V	0	0.0%	38	84.4%	0	0.0%	7	15.6%	0	0.0%	45
	D & Short V	0	0.0%	38	76.0%	2	4.0%	10	20.0%	0	0.0%	50

Table 9 illustrates that there is very little difference between roots and non-roots in the lexical distributions of tone across syllable classes. Therefore, this suggests that the intensifier reduplication data above in (5) is not pointing to a general fact about Thai affixes, but a specific fact about that reduplicant, as Ruangjaroon's analysis assumes. While the root-specific hypothesis explains why we see evidence for onset-tone restrictions in the word game, but not in the reduplication, it is not supported by a corresponding pattern in the lexical frequencies of roots versus non-roots.

While the evidence for the root-restriction hypothesis doesn't hold up, the evidence for alternations favors the hypothesis that the high-tone restrictions in unchecked syllables are encoded in the grammars of Thai speakers. Recall that there is a possible explanation for the non-application of onset-tone restrictions in reduplication.

Ruangjaroon posits that faithfulness to the H tone in the reduplicant outranks the general markedness constraint driving the onset-tone restriction. However, there is no plausible explanation for the avoidance of the high-tone sequences in the word game. Therefore,

the evidence of alternations appears to be in favor of the grammatical status of the onset-high tone restrictions in Thai.

2.5 Conclusion

This chapter has presented the empirical facts of consonant-tone interaction in Thai based on lexical gaps. Ruangjaroon (2006) showed that high tone is unattested following both unaspirated and voiced stop onsets in unchecked syllables. In checked syllables, the tonal contrast is reduced from a five-way contrast to a two-way contrast. If the vowel is long then only low and falling tones are attested; if the vowel is short then only low and high tones are attested. This two-way contrast is reduced further if the onset is an unaspirated or voiced stop, so that only low tone is attested.

The last two sections of this chapter took a more detailed look at the lexical gap and at morpho-phonological alternations involving consonant-tone interaction in Thai. Lexical frequency statistics offered an improved, quantitative approach, which clarified the nature of the lexical gaps in a few ways. First, not only high tone, but also rising tone was found to be under-represented following unaspirated and voiced stops in unchecked syllables. Second, a detailed look at loanwords and onomatopoeia reveal that the high-tone restrictions are not existent in these word classes. Third, certain consonant-tone combinations are completely unattested (mid and rising tone in checked syllables, for example) whereas other combinations are under-represented (high and rising tone following unaspirated and voiced stop onsets in unchecked syllables, for example). These observations may be facts about the synchronic grammar of Thai speakers. Alternatively, these more subtle observations may not be encoded in the grammar.

The focus of the final section, and indeed of the rest of this dissertation was to determine whether and to what extent the high-tone (and rising-tone) restrictions following unaspirated and voiced stops in unchecked syllables are encoded in the grammar. Evidence from morpho-phonological alternations, while limited, suggests that the high tone restriction is real since high tone is avoided following voiced and unaspirated stops in a word game. The following chapters build on this via experiments. Chapter 3 assesses the phonetic realization of the two classes of stops involved in the restrictions (voiced and unaspirated), suggesting a unified analysis under the feature [+constricted glottis]. Chapter 4 then moves to judgment experiments that test whether speakers exhibit a dispreference for nonce words that contain sequences of unaspirated or voiced stops preceding high or rising tone.

Chapter 3 – An Acoustic Investigation of Onset-Tone Interaction

3.1 Introduction

This chapter aims to establish a phonetic explanation for the onset-tone restrictions presented in Chapter 2. An acoustic study confirms that the onsets that are banned preceding high tone in unchecked syllables in Thai are articulated with laryngeal constriction. The study capitalizes on the fact that a laryngealized consonant affects the onset of a following vowel via coarticulation. The results suggest that unaspirated and voiced obstruents in Thai should be treated as [+constricted glottis]. Furthermore, a phonological constraint banning sequences of [+constricted glottis] segments and H tone can explain the lexical gaps presented in Chapter 2 that involved unaspirated and voiced obstruent onsets.

The use of [+constricted glottis] constitutes an amendment to previous phonological analyses of consonant-tone interaction in Thai. Lee (2008) and Ruangjaroon (2006) utilize the feature value [–spread glottis] to group unaspirated and voiced obstruents together, excluding aspirated obstruents. However, it is commonly assumed that the feature [spread glottis] is privative and that only the ‘+’ value is active in phonological processes (Lombardi 1991:27; Clements and Hume 1995:270; Kehrein 2002:66; Hall 2007:317-318). Furthermore, Lee (2008) notes that Thai would be the only language in his cross-linguistic survey where the feature [–spread glottis] is active in consonant-tone processes cross-linguistically. This chapter argues for an alternative position that is consistent with a privative treatment of the features [constricted glottis] and [spread glottis], that Thai unaspirated and voiced obstruents are [+constricted glottis].

A second major finding of this study is that there is a phonetic distinction between

glottal stops and the laryngealized (unaspirated and voiced) obstruents. However, this phonetic distinction is not represented in Thai phonology. The acoustic results show that glottal stops raise both F0 and spectral tilt in a following vowel, while unaspirated and voiced stops *lower* F0 and spectral tilt in a following vowel. This difference is explained by appealing to two distinct modes of glottal constriction: Glottal stops involve an articulation similar to tense phonation, whereas laryngealized obstruents involve an articulation similar to creaky phonation. Importantly, this phonetic difference is not one that the phonological system of consonant-tone interaction in Thai is sensitive to. High tone is unattested in Thai following both [ʔ] and the laryngealized obstruents. As a result, the phonological system involves abstraction across these different phonetic modes of glottal constriction, unifying them under a single feature value, [+constricted glottis]. A single constraint that bans [+constricted glottis] preceding high tone can explain the high-tone gaps then.

While a number of previous studies have reported laryngealization of Thai voiced and voiceless unaspirated stops, few have provided instrumental evidence of laryngealization. Abramson (1962:4) notes that “pre-vocalic /p t k/ are pharyngealized”. Harris (1972:11) labels the unaspirated series as glottalized. He describes them as “pronounced with simultaneous oral and glottal closures... so that the glottal release is not heard”. Gandour & Maddieson (1976:244) note that voiceless unaspirated /p/ is “often described as accompanied by glottal constriction”. They conclude that the voiceless unaspirated series are tense stops and not ejectives.

Voiced stops have also been reported as glottalized by Harris (1972:14), who noted that “utterance initial voiced stops and approximants are usually preceded by weak glottal

closures.” While the combination of glottal constriction and voicing is usually associated with implosiveness, Harris adds that even though there is some glottalization, these voiced stops are not produced as implosives. Ladefoged & Maddieson (1996:55) describe voiced stops in Thai as occurring with “stiff, or even creaky voice”. They add (p. 78) that voiced stops in Thai “are often accompanied by downward movement of the larynx that make them slightly implosive”. None of the above authors presented any instrumental evidence of laryngeal activity however, instead relying on impressionistic observations.

In addition to the impressionistic observations outlined above, there is quantitative evidence that indicates voiced stops may be laryngealized in Thai. Voiced stops lower F0 for about the first 50 ms in a following vowel in Thai (Gandour 1974b), suggesting a phonetic explanation for the phonological ban on high tone following voiced stops. On the other hand, studies on interaction between voiceless stops and F0 in Thai have yielded unclear results that diverge in different directions. Erickson (1975) found that for eight of eleven native Thai speakers, F0 was raised following voiceless aspirated stops relative to voiceless unaspirated stops. However, the remaining three speakers showed the opposite pattern, with F0 raised following voiceless unaspirated stops. Gandour (1974b) reported that voiceless aspirated stops also lower F0.

The effect where voiced stops lower F0 has been documented widely even in non-tonal languages such as English (Hombert et al. 1979). Phonological accounts have utilized a single feature for low tone and voicing (Halle & Stevens 1971; Bao 1990; Bradshaw 1999). Halle & Stevens’ system uses the features [stiff vocal cords] and [slack vocal cords] to refer to the vertical tension in the vocal cords. Increased stiffness raises F0 and inhibits voicing, while increased slackness lowers F0 and allows voicing to occur

more easily. The stiff/slack distinction simultaneously explains the high/low tone distinction on vowels as well as the voiced/voiceless distinction in consonants, thus offering a possible explanation for the correlation between voicing and low tone and voicelessness and high tone, cross linguistically.

While there is often correlation between phonation types and tone, laryngeal constriction can be articulated in a number of different ways, each of which can have distinct effects on F0 (Stevens 1977; Gordon & Ladefoged 2001). At the articulatory level, [ʔ] can be realized with creaky phonation on an adjacent vowel or as a complete closure without any creakiness (Ladefoged & Maddieson 1996:75). Creaky phonation is most commonly associated with lowered F0; however, there are reports of glottalization raising F0 as well (Maddieson 1977; Hombert et al. 1979; Kingston 2005), indicating that the two are phonetically independent, at least in part. A more articulated system can be found in Esling & Harris (2005) and Edmondson & Esling (2006), who model the larynx using a total of seven independent articulatory parameters. Among configurations with glottal constriction, they note “creaky”, “tense” and “harsh” as distinct configurations of laryngeal constriction. While creaky constriction lowers F0, tense and harsh constrictions raise F0. Harsh voice is typically associated with constriction of the ventricular folds (located above the vocal folds), an articulation that is common in glottal stops. The use of “creaky” or “harsh” to describe glottal stops is unusual, as these terms are normally reserved for phonation on vowels. The use of these terms with an obstruent here is meant to indicate that a laryngeal constriction resulting in a given kind of phonation can be applied to an obstruent. The glottal closure is articulated with the same muscular movements as the laryngeal constriction made during the corresponding phonation type.

The variation in the effects of laryngeal constriction on F0, described above, is mirrored in phonology. Lee (2008) notes that the feature [+constricted glottis] in a preceding consonant neutralizes high tone to low tone in Burmese, but it also neutralizes low tone to high tone in Mulao. 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 F0.

This variation in the articulation of laryngeal constriction introduces another layer of complexity: Not only must its presence be established, but it is also necessary to distinguish among various types of laryngeal constrictions. Despite this variation in the effects on F0, there are two observations in Thai that suggest a single null hypothesis. The first are the impressionistic claims that voiced and voiceless unaspirated stops are laryngealized and sometimes creaky. The second is the phonological ban on high tone following these same consonants. Assuming a lack of transparency between phonetics and phonology, it is expected that the consonants that are unattested preceding high tone should lower F0. As such, the onsets are expected to be articulated with a laryngeal constriction of the creaky type, since this lowers F0. This is the situation with unaspirated and voiced stops in Thai. However, the alternative hypothesis, that the phonology does not match the phonetics is also possible. In this case, onsets that raise F0 would be banned preceding high tone; this is the case with the glottal stop in Thai. This phonetic variation does not play a role in the phonology however. The key phonological feature value, [+constricted glottis], groups [ʔ] and unaspirated and voiced obstruents together, regardless of the phonetic details.

While laryngeal constriction is the focus of this chapter, recall that [h] onsets cannot occur with high tone in Thai. Aspirated stops and [h] are similar in that both occur with the glottis spread. This configuration can result in aspiration or breathiness (Halle & Stevens 1971), the latter of which usually lowers pitch (Laver 1994:477-478; Gordon & Ladefoged 2001). However, if the phonological tone restriction is based only on details of phonetic effects on F0, then a featural difference between [h] and the aspirated stops must exist. In order to account for this difference, the feature [slack vocal folds] (referred to as [slack] hereafter) is used to distinguish [h], which is [+slack], from aspirated stops, which are not [+slack]¹⁷. The feature, [slack] was first proposed, along with the feature [stiff], by Halle and Stevens (1971) as a way to capture the fact that tone in vowels and voicing in consonants are articulated in the same manner. When the vocal folds are stiff, F0 is raised, and voicing is somewhat inhibited. On the other hand, when the vocal folds are slack, F0 is lowered and voicing can occur relatively more easily. Therefore a feature value of [slack] on [h] is consistent with F0-lowering, and a phonological ban exists in Thai against [slack] onset-H tone sequences.

In order to confirm the presence and type of laryngealization, this study offers measurements of spectral tilt, in addition to F0, in the vowel immediately following onset consonants (Gordon & Ladefoged 2001).¹⁸ Spectral tilt refers to the difference in amplitude between higher formants and either one of the harmonics of F0 or one of the lower formants. In modal phonation, there is a relatively larger amount of energy in lower

¹⁷ It is somewhat unusual for [h] to be [+slack]; Halle and Stevens (1971) treat [h] as [+stiff, –slack], noting that [+slack] implies voicing in their system (i.e. voiced [ɦ]). However, their system also does not distinguish [h] from the aspirated stops via any laryngeal features. Since [h] and the aspirated stops are distinguished in Thai, some feature must distinguish them. The fact that [slack] tends to occur with lowered F0 indicates it may be the relevant feature here.

¹⁸ Jitter was also measured (Perkins 2011), however the results were not statistically significant and so they are not reported here.

formants and relatively less energy in the higher formants. When the glottis is constricted to produce creakiness, the higher formants gain energy relative to lower formants, resulting in lower spectral tilt. When the glottis is spread, on the other hand, the higher formants have considerably less energy, resulting in higher spectral tilt (breathy voice). The differences in spectral tilt for creaky, modal and breathy phonation are summarized schematically in Figure 2 below.

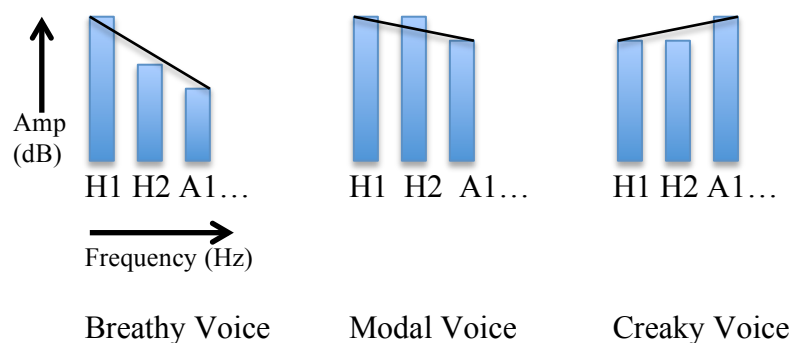


Fig. 2. Spectral Tilt Schematized (H1 is the 1st harmonic of F0, H2 the 2nd harmonic of F0, A1 is the 1st formant).

The difference between creaky and modal phonation can be seen in the spectrograms shown in Figure 3 below. Note that following [p] (left) there is relatively more energy in the higher formants near the beginning of the vowel (the arrows point to F4). This indicates that [p] is inducing creaky phonation in the following vowel. However, following [m], only F1 and F2 are relatively dark, with F3 and F4 being relatively faint. Likewise F0 is darker following [m] than it is following [p], an additional indication that relatively more energy is concentrated in the higher formants in [p].

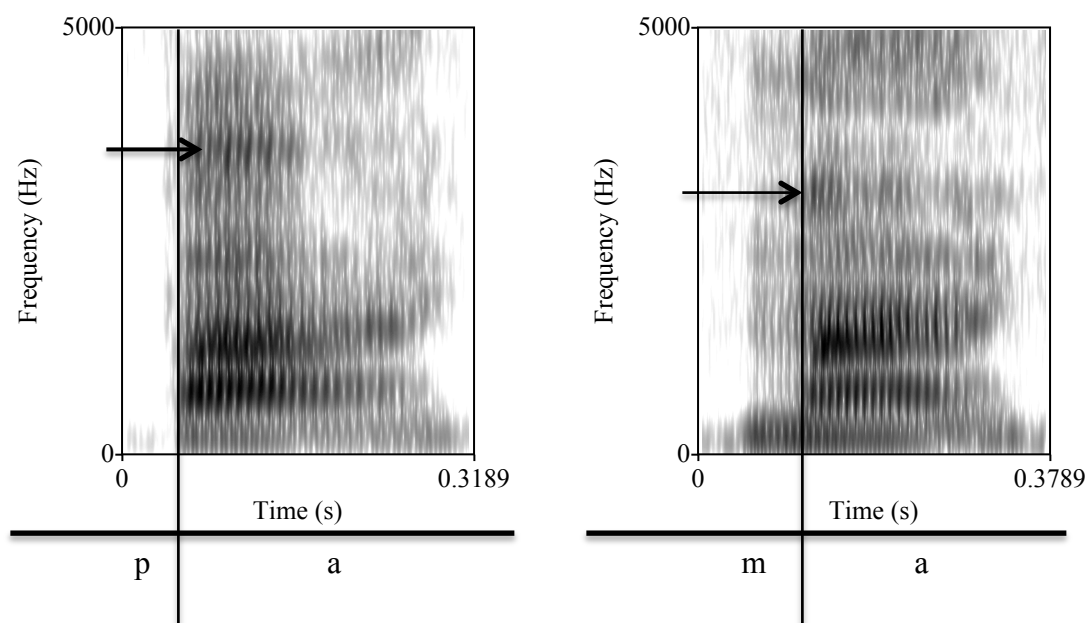


Fig. 3. Spectral Tilt following creaky [p] (left) and following modal [m] (right).

Spectral tilt is predicted to be a better indicator of laryngealization than F0 in tone languages because F0 is involved as the main cue in creating a tone contrast. F0 effects from consonants are minimized in tone languages compared to non-tone languages; Hombert et al. (1979) found that F0 was lowered following voiced consonants for 40 to 60 ms in Yorùbá compared to a duration of greater than 100 ms in English. Similarly, Gandour (1974a) found F0-lowering durations of 30 to 50 ms for voiceless and voiced consonants in Thai. While F0-lowering effects may be minimized, spectral tilt, on the other hand, is not involved as a primary cue in Thai.¹⁹ In categorical perception, it is expected that listeners will ignore differences that are not involved in contrasts (DiCanio 2012). Extending this same principle to production would predict that speakers of tone languages would be unaware of spectral tilt effects from consonants, allowing

¹⁹ Notably, in languages where phonation is contrastive, spectral tilt effects may in fact be directly involved in creating contrast on vowels. A prediction of this is that spectral tilt may be more regulated and therefore coarticulatory effects on spectral tilt from the consonants may be minimized in these languages.

coarticulatory effects to dominate. As such, this would lead to spectral tilt being a stronger indicator of laryngeal constriction in consonants than F0. This prediction is confirmed in the experiment: Spectral tilt results are much more significant indicators of laryngeal constriction than F0 in Thai (see Section 3.3).

3.2 *Methods*

3.2.1 *Stimuli*

A list of stimuli was constructed as follows. Since creakiness is hypothetically associated with voiceless unaspirated and voiced obstruent onsets but not with voiceless aspirated onsets, the stimuli included words that differed in which of these three onsets they contained. Stimulus words were placed between spaces²⁰ in sentences (following Morén & Zsiga 2006) to ensure natural pronunciations in stressed positions. Each participant read the stimuli via a Microsoft PowerPoint presentation. A pair of example slides are shown below in Figure 4, as they were presented to the participants.

²⁰ Thai orthography does not require the use of spaces between words; they are optional.

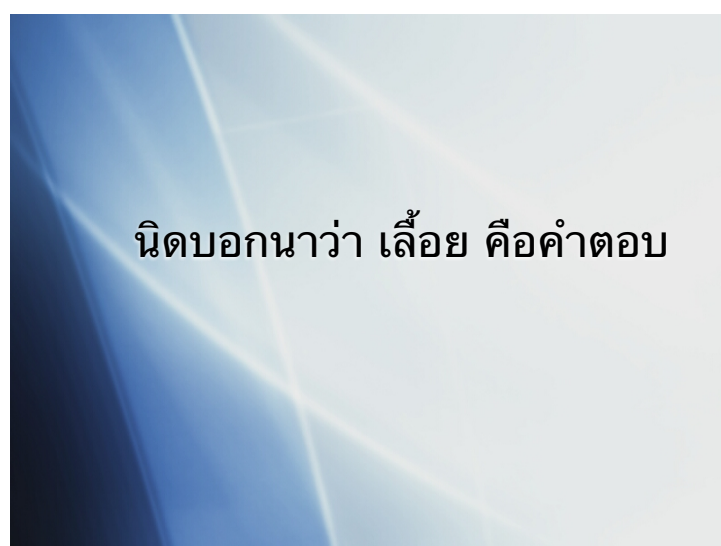
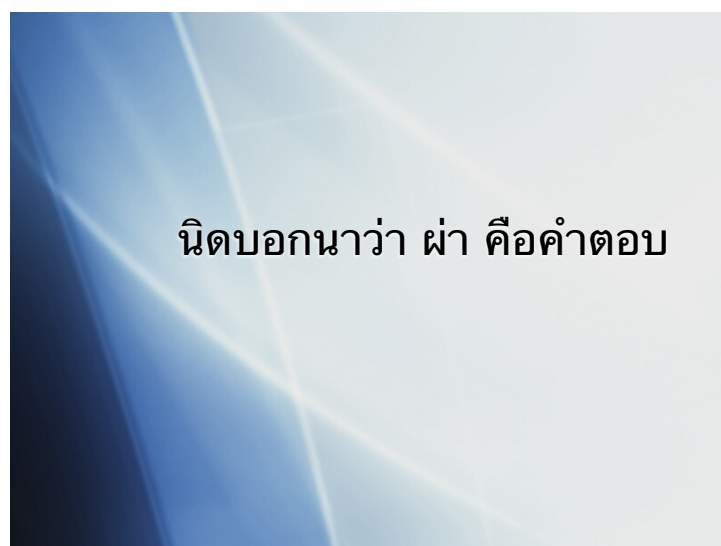


Fig. 4. Two examples from the slideshow. Stimuli are separated by spaces. The stimulus “ผ่า”(above), pronounced [pʰà:], means “to cut”. The distractor “เลื้อย” (below), pronounced [lùuaj], means “to creep”.

In addition to the oral stop series, [ʔ] and [h] were included in the study for two reasons: First, [ʔ] and [h] also involve laryngeal articulation. Second, like unaspirated and voiced stops, [ʔ] and [h] do not occur preceding high tone in unchecked syllables. As previously mentioned, there are multiple possible ways to articulate [ʔ]. Two such articulations are considered here. If [ʔ] is articulated with creaky laryngeal constriction,

F0 and spectral tilt will be lowered, just like voiceless unaspirated and voiced onsets.

Alternatively, if glottal stops in Thai are produced with a constriction of the ventricular folds (“harsh” laryngeal constriction), then F0 would be raised, rather than lowered.

Predictions for spectral tilt are less clear; while creaky voice lowers spectral tilt, there is no research that has determined the effects of tense or harsh laryngeal constriction on spectral tilt. With respect to [h], I assume it is [+slack] and therefore it is expected to lower F0. Since it is produced with breathiness, H1–A1 should be raised.

Table 10 below summarizes expectations for each onset class based on the discussion above, where it is expected that phonetic results will support the onset-tone gaps. Both alternative hypotheses for harsh and creaky glottal stops are included as well; only one of these can be correct for Thai, but it is not clear *a priori* which is correct.

Table 10
Phonetic hypotheses for each onset type²¹

Onset Type	Occurs With H Tone?	Hypothesis – F0	Hypothesis – H1–A1
Voiceless unaspirated stops & affricates [p t k tʃ]	No	Lowered F0	Lowered H1–A1
Voiceless aspirated stops & affricates [p ^h t ^h k ^h tʃ ^h]	Yes	No effect on F0	No effect on H1–A1
Voiced stops [b d]	No	Lowered F0	Lowered H1–A1
Nasal stops [m n ŋ]	Yes	No effect on F0	No effect on H1–A1
Glottal stop [ʔ] if creaky	No	Lowered F0	Lowered H1–A1
Glottal stop [ʔ] if harsh	No	Raised F0	Unclear
Glottal fricative [h]	No	Lowered F0	Raised H1–A1

To enable statistical testing, paired comparisons were constructed by identifying near minimal pairs that differed only along a single laryngeal dimension. All possible pairings of the three different manners of oral stop yielded the first three comparisons. Bilabial

²¹ Other sounds that occur in Thai onsets include [l r j w f s]. These onsets were not considered in this study. Instead, only [m] was used, forming minimal comparison with the bilabial oral stops that were used.

onsets, rather than coronal, palatal, or velar onsets, were used in building stimuli because bilabial place is the most easily recoverable among each place of articulation (Sussman et al., 1991) and they do not involve any coarticulation with (unround) vowels.

Additionally, the Thai lexicon has a large number of words with bilabial onsets, allowing for more stimuli corresponding to real Thai words. For each of the six onsets, a vowel with each of the five tones was used in composing stimuli, resulting in a total of thirty stimulus categories. Monosyllables were built using the long low vowel [a:], thus controlling for vowel quality. Codas were not used since they affect the pitch on the preceding vowel.

While the [b] vs. [p^h] comparison involves two laryngeal differences (voicing and aspiration), it was included since it directly addresses the hypothesis that [b] is laryngealized and [p^h] is not. The [ʔ] vs. [h] comparison is the only one that removes oral place as a factor. It is not clear whether [ʔ] will be creaky or harsh, and different predictions are made in each case. If [ʔ] is creaky, both [ʔ] and [h] will lower F0, but no prediction is made which will lower F0 to a greater degree. However, a much lower H1–A1 is predicted for a creaky [ʔ] relative to a breathy [h]. If [ʔ] is harsh, then [ʔ] is predicted to be associated with raised F0 relative to [h]; it is unclear what effect harsh phonation has on spectral tilt, so no prediction is made in that case. In the [ʔ] vs. [p] comparison, if both [ʔ] and [p] are creaky, then there should be no difference in F0 and spectral tilt. If [ʔ] is harsh, then F0 should be much higher following [ʔ] relative to [p]. The [h] vs. [p^h] comparison is included to test the hypothesis that [h] is [+slack], while [p^h] is not; it is expected that F0 will be lower in [h] and a greater degree of breathiness will be seen in [h], thus raising H1–A1. Finally, the [p^h] vs. [m] comparison is included as

a baseline to confirm that [p^h] (like [m]) is not laryngealized. These seven pairwise comparisons are summarized in Table 11 below, along with the specific hypotheses for each concerning phonation and F0 differences induced at the onset of a following vowel. Recall that the main hypothesis is that [b] and [p], but not [p^h], are laryngealized.

It should be noted that this grouping of voiced and unaspirated stops as a class, is specific to Thai. Cross-linguistically, voiced stops are associated with lowered F0 relative to plain (unaspirated) stops. In addition, many languages have lowered F0 associated with sonorants like [m] and raised F0 associated with aspirated stops like [p^h] (Bradshaw 1999; Lee 2008; Tang 2008). As a result, the baseline comparison between [p^h] and [m] will yield F0 differences in many languages; however, Thai is not expected to be one of these if glottal constriction is the only factor affecting F0.

Table 11
Pairwise comparisons for onsets

Comparison	Hypothesis
[p] vs. [p ^h]	[p] lower H1–A1 & lower F0
[p] vs. [b]	No H1–A1 or F0 difference
[b] vs. [p ^h]	[b] lower H1–A1 & lower F0
[ʔ] vs. [h]	Creaky [ʔ]: [ʔ] lower H1–A1 Harsh [ʔ]: [ʔ] higher F0
[ʔ] vs. [p]	Creaky [ʔ]: No H1–A1 or F0 difference Harsh [ʔ]: [ʔ] higher F0
[h] vs. [p ^h]	[h] higher H1–A1 & lower F0
[p ^h] vs. [m]	(Baseline) No H1–A1 or F0 difference

Not all of the stimuli formed in the manner described above corresponded to a Thai word. In cases where no Thai word existed, the nonce stimulus was still used, but in addition, Thai words were selected that differed only in that they contained a glide coda ([w] or [j]). In a few cases, it was necessary to use a short vowel with glide coda due to lexical restrictions. These Thai words were included in case the speakers had trouble

producing the CV: nonce word versions, and were to be included in the analysis only in that case, as confirmed by statistical testing. In one case (p^há:), a Thai word existed that contained an optional [r] trill following the [p^h] onset. This word was included as part of the back-up stimuli rather than a similar word with glide coda since there was no word pronounced as [p^há:] in Thai. However, there was a possibility that the speakers would pronounce a [p^hr] cluster, and that this would affect F0 and spectral tilt during the onset of the following vowel. Tokens with [p^hr] clusters would only be included in the analysis if statistical tests showed that [r] has no effect on the creakiness of the following vowel and if a larger number of errors were made on the nonce [p^há:] syllable. Table 12 below shows the stimuli.

Table 12 – Experimental word stimuli

CV Stimuli					
Test Stimuli	Mid	Low	Falling	High	Rising
Aspirated	p ^h a: "take"	p ^h à: "cut"	p ^h â: "clothes"	p ^h á: (nonce)	p ^h ǎ: "a cliff"
Unaspirated	pa: "throw"	pà: "forest"	pâ: "aunt"	pá: "father" (loan)	pǎ: "father" (loan)
Voiced	ba: "bar" (loan)	bà: "shoulder"	bâ: "crazy"	bá: (nonce)	bǎ: (nonce)
Sonorant	ma: "come"	mà: (nonce)	mâ: "grandma" (loan)	má: "mother" (loan)	mǎ: "dog"
?	?a: "aunt"	?à: (nonce)	?â: "spread"	?á: (nonce)	?ǎ: (nonce)
h	ha: "fun"	hà: "cholera"	hâ: "five"	há: "ha!" (loan)	hǎ: "look for"

Backup Stimuli					
Test Stimuli	Mid	Low	Falling	High	Rising
Aspirated	N/A	N/A	N/A	p ^h (r)á: "knife"	N/A
Unaspirated	N/A	N/A	N/A	N/A	N/A
Voiced	baj "a leaf"	N/A	N/A	none	none
Sonorant	N/A	māj "new"	māj "widow"	máj (question particle)	N/A
?	N/A	?à:w "a bay"	N/A	none	none
h	N/A	N/A	N/A	N/A	N/A

A single Thai frame sentence, written in Thai orthography, was used with the experimental word stimuli inserted. Morén & Zsiga (2006) used this frame sentence in

their study of Thai coda-tone interaction. An example is given in (9), with the stimulus word underlined.

(9) Experimental sentences

nít bək na: p^ha: k^hu: kamtəp

Nit tell Naa take be answer

“Nit told Naa that ‘take’ was the answer”

These sentences place the stimulus words in stressed positions. The words both preceding and following the stimulus word were chosen with mid tone because mid tone has no coarticulatory effect on the tone of adjacent syllables (Morén & Zsiga 2006).

The thirty CV: stimuli and the six back-up stimuli composed the complete experimental stimuli. Distractor stimuli were added that met the following conditions: First, they did not contain any of the onsets used in the experimental stimuli listed above. Second, they did not contain the low vowel [a]. Codas were allowed. They were all Thai monosyllabic words, randomly selected from Slayden’s (2013) online Thai dictionary. Twenty-six distractors were included, yielding a total of sixty-two token sentences. The sixty-two stimuli words were translated into Thai script, as was the host sentence. The stimulus word was separated from the rest of the sentence by spaces, so as to allow for the intended reading of the sentence. Eight repetitions of the stimuli were presented via a PowerPoint slideshow. Microsoft Excel was used to randomize the stimuli presentation order between repetitions and a single slideshow file was created. This presentation was shown to each participant.

3.2.2 *Participants*

Three male native speakers of Standard Thai were recruited via social networking. All three grew up in Bangkok speaking Standard Thai as their native language. All had parents who also spoke Standard Thai. They all listed English as a second language that they were able to use proficiently but not at a native-speaking level; the author's impression was that C & T have a greater degree of fluency in speaking and listening to English whereas Speaker K had a very low fluency in both speaking and listening in English. None of the speakers had any physical or cognitive language impairment, nor any illnesses that would have affected their speech at the time of recording. Speaker C was thirty years old and moved to Los Angeles at age twenty. He had visited Los Angeles many times prior to moving there as well. He resided in New Brunswick, NJ at the time of recording. Speaker T was thirty-four years old and lived in Thailand until he moved to the United States at age thirteen. He had visited Thailand three times for periods of about two weeks since then. He resided in New Brunswick, NJ at the time of recording. Speaker K was thirty-nine years old and had lived in Nakhon Pathom and Nonthaburi provinces, both on the outskirts of Bangkok. He had spent almost his entire life in Thailand and had visited the United States on two separate occasions for a total of three months.

3.2.3 *Recording*

Each speaker participated in a single recording session in the sound-attenuated booth at the Rutgers University Phonetics Lab in New Brunswick, New Jersey. The speakers read all the sentences off a computer screen inside the booth that displayed the Thai

sentences. An Audio-Technica AT4040 microphone with pop filter was used. It was connected via an XLR cable to an Applied Research & Technology Tube MP amplifier. A second XLR cable connected the amplifier to an M-Audio Delta 1010 sound card; digitization used ASIO drivers. The sound was digitized on a custom-built PC running Windows XP. Audio files containing the stimuli were created at a sampling rate of 44100 Hz using GoldWave version 5.06. The files were resampled to 16000 Hz in order to prevent overloading of the signal (Ladefoged 2003:95) prior to analysis in Praat (Boersma & Weenink 2005).

A short practice session was done in order for the speakers to get used to the sentences. The speakers were also instructed that they may not recognize some of the Thai words (the nonce words), but that they should pronounce them as accurately as they could. For Speaker C, only four or five tokens of each test stimulus were recorded due to an error that halted recording in the middle of the fifth randomized run-through of the stimuli. For Speaker T, eight tokens of each stimulus were recorded. For Speaker K, six or seven tokens of each stimulus were recorded. The recording session took approximately one hour per participant.

3.2.4 *Measurement*

Vowels in the test stimuli words were segmented via Praat and saved in a text grid file. The boundaries of segmented vowels were determined based on the point where some formants were no longer clearly discernable (including higher formants such as F4 and F5). Figure 5 shows a segmented spectrogram that illustrates a typical example of how vowels were segmented. The F2, F4 and F5 formants are no longer clearly

discernible beyond the point where the vowel offset is marked.

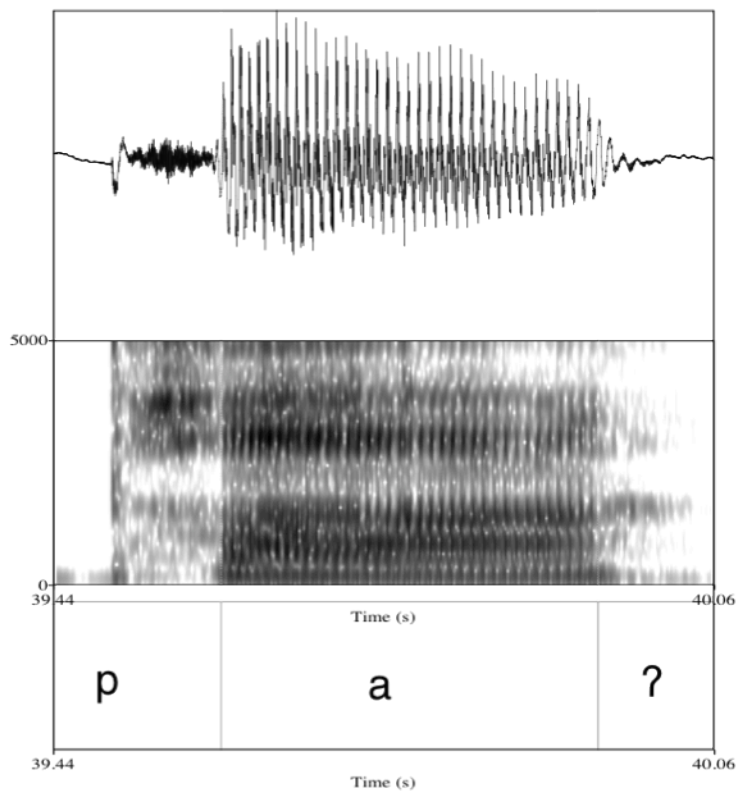


Fig. 5. Example of vowel segmentation.

Two measurements are made at the onset of a following vowel: F0 and spectral tilt (Gordon & Ladefoged 2001; Ladefoged 2003:169-181). Spectral tilt is measured by taking the difference of the amplitude of either the first harmonic or the first formant with the amplitude of one of the higher formants. H1–A1 is measured here (following Keating & Esposito 2007). This involves the difference between the amplitude of the first harmonic of F0 (H1) and the amplitude of the first formant (A1). Creaky voice is typically produced in such a way that the time that the glottis is open is shorter than for modal voice over a given glottal pulse period (see Figure 2 above). Because of this, the amplitude of higher formants is relatively higher in creaky voice (Holmberg et al. 1995)

and so the difference $H1-A1$ is close to zero typically.

In order to measure spectral tilt, the vowels are broken into ten equally-timed segments. For each of these segments, a long-term average spectrum (LTAS) is taken within Praat. The amplitudes of the first harmonic and first formants are then measured and their difference is calculated, yielding the spectral tilt for each segment of the vowel. Only the first of these ten segments is used in the data analysis, since this segment is closest to the consonant, and therefore is most likely to show effects of laryngealization due to the consonant.

F0 is measured via extraction of pitch values at 10 ms intervals over the entire length of the vowel. Gandour (1974b) notes that consonant coarticulation with vowels in Thai occur over the first 50 ms of the vowel. However, only the first F0 measurement is used in the analysis, since it is closer to the onset consonant than the other measurements, and therefore most likely to include an effect, if present. Spectral Tilt and F0 measurements were automated using a Praat script adapted from diCanio (2007). The measurements are automatically entered into a text file for further analysis.

Statistical analysis involved ANOVA's with speaker, tone and onset as independent factors. In this experiment, one ANOVA was used for each of the dependent variables (spectral tilt and F0) to test for statistically significant effects due to onset type across speakers and tones. Significance level of $\alpha=0.05$ was used. If a significant effect was found, then a simple analysis for specific hypotheses was tested next. In the simple analysis, filters were applied to the data to look for effects with a given two-way comparison from Table 3 in mind. For example, in order to test for a significant effect between [p] and [p^h], the ANOVA was performed on only those tokens with [p] and [p^h]

onsets. Seven such comparisons were made as outlined in Table 11 above. Bonferroni adjustments were made to account for the possibility of inflating the chance for Type-1 error by testing multiple hypotheses on the same data set. For example, since [p] is involved in three of the comparisons, the significance level α is adjusted to $\alpha/3 = 0.05/3 = 0.0167$.

In cases where ANOVA's revealed significant interactions, two-tailed independent sample t-tests were conducted testing the specific hypotheses of the experiment. Whenever significant effects due to tone and/or speaker were discovered in the filtered ANOVA's, multiple t-tests were conducted over each speaker-tone group, of which there are fifteen in total (five tones \times three speakers). Otherwise, if no significant effect was found for speaker or tone in an ANOVA, then those categories were ignored and t-tests were performed across speakers and/or tones.

3.2.5 *Data Accuracy*

Prior to statistical analysis, the recorded tokens were checked for accuracy. Of a total of 690 total tokens, 15% contained errors. 100 tone errors were discovered and 6 consonant errors were discovered. These errors were determined by visual inspection of the pitch tracks in Praat by the author (a non-native speaker of Thai). Tokens with errors were excluded from the analysis since tone and onset are crucial factors in the experimental design. Table 13 illustrates that most of the errors were made on nonce words, with nearly as many made on loans, while only 4% of native Thai words were produced with errors. Table 14 reports errors as a function of speaker.

Table 13
Errors by Type

Type	# of Tokens	# of Errors	% Error
Nonce	134	57	43%
Loans	113	34	30%
Onomatopoeia	18	0	0%
Native	425	15	4%

Table 14
Errors by Speaker

Speaker	# of Tokens	# of Errors	% Error
C	168	16	10%
T	288	57	20%
K	234	33	14%

These results indicate that the nonce words were not very effective at eliciting the intended tones. Two words accounted for 36 errors alone: The Thai interjection [há:] was consistently read with falling tone rather than high tone in all 20 tokens and so it was discarded completely. This finding seems too systematic to be an error, and so it is more likely that the Thai orthographic word²² used to elicit [há:], is pronounced with falling tone rather than high tone, at least for the three speakers in this study. While Ruangjaroon (2006) lists this word in her appendix without noting it as a loan word (she also transcribes it with high tone), a native Thai speaker²³ has informed me that it is a loan from the English interjection “ha!”. For this reason, it was classified as a loan word.

Likewise, the nonce word [p^há:] was produced incorrectly in 16 of 18 tokens. Ten errors from Speakers C and T were produced with falling tone. Another single error by Speaker T was produced with high tone but with an [f] onset instead. The remaining five errors were made by Speaker K, who inserted a liquid [l] following the initial [p^h], yielding a [p^hl] cluster in all but one of his utterances. The two correct utterances were

²² Tone is marked orthographically in Thai.

²³ This same Thai speaker judged it as high and not falling tone.

made by Speakers T and K, and were retained. An additional three nonce words, two of which also contain high tone, were produced with at least a 50% error rate. These words were [bá:], [ʔá:] and [ʔà:]. In all cases, the most common error was for the tone to be produced as falling tone, although mid and rising tones were also produced. The large percentage of high-tone mispronunciation resulted in a very large number of high tone tokens being excluded, making statistical analysis within the high-tone category impossible in many cases. Notably, the three nonce words with the lowest error rate ([bǎ:] 22%, [mà:] 20% and [ʔǎ:] 11%) also do not contain high tone.

Since the nonce words had such high error rates, the backup native Thai tokens were considered. A statistical test was conducted in order to test whether the presence of a glide coda had a significant effect on F0 or spectral tilt. If no effect would be discovered, then the tokens [ʔà:w], [máj], [mâ:j], and [mǎj] would replace their nonce correspondents without codas in the analysis, each of which was produced with a greater number of errors. The token [baj] was not considered as a replacement to the English loan [ba:], since the latter was produced without any errors.

An ANOVA using onset, tone, speaker and coda as independent variables was performed, with the result that, while the coda had no effect on F0 [$F(2, 467) = 2.7307$, $p = \text{n.s.}$], it did affect spectral tilt [$F(2, 462) = 166$, $p < 0.001$] and so the tokens with codas were not used. A second test was conducted after first removing the tokens with short vowels, in order to allow for the possibility that only the codas following a short vowel were responsible for the previous result. The second test again confirmed that codas affected spectral tilt [$F(2, 419) = 56.8$, $p < 0.001$]. Additionally, an effect was discovered on F0 this time [$F(2, 421) = 3.92$, $p < 0.05$]. This indicates that glide codas do have a

significant effect on the creakiness at the onset of the preceding vowel and so the tokens with codas were not included in the analysis. This is a surprising result –a long-distance coarticulatory effect of codas on the vowel onset is not expected.

One further test was conducted to test the effect of a stop-liquid cluster on the onset of a following vowel. This test was conducted since many more errors were made in producing [p^há:] than in producing [p^hrá:]. Spectral tilt [$F(1, 13) = 13.75, p < 0.01$] was affected significantly by the presence of the liquid, while F0 [$F(1, 13) < 1, p = \text{n.s.}$] was not. This indicates that liquids affect the creakiness at the onset of a following vowel and so the [p^hrá:] tokens were not included in the analysis.

3.3 Results

Both spectral tilt and F0 are significantly affected by the onset, as hypothesized. The independent factors, tone and speaker also significantly affected spectral tilt and F0. Significant interactions for F0 and spectral tilt were discovered between onset and tone, as expected; however, interactions were also significant between onset and speaker, and speaker and tone, implying that different combinations of the independent factors (onset, speaker, and tone) must be treated separately in the statistical analysis. The results of ANOVA's for both dependent variables are summarized in Table 15 below.

Table 15
ANOVA Results for Spectral Tilt and F0
(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Dependent Variable	Onset	Speaker	Tone	Onset*Tone	Onset*Speaker	Speaker*Tone	Onset*Speaker*Tone
Spectral Tilt	**	**	**	**	**	**	n.s.
F0	**	**	**	*	*	**	n.s.

Section 3.3.1 presents evidence that voiced and unaspirated stops and the unaspirated affricate [tɕ] are laryngealized in Thai. Section 3.3.2 presents results for the glottal stop [ʔ] and fricative [h].

3.3.1 The Oral Stops: *b, p, p^h*

Voiced [b] and unaspirated [p] have significantly lower H1–A1 and F0 than aspirated [p^h], as hypothesized. This result confirms that [p] and [b] are laryngealized, inducing creaky voice in a following vowel. Since tone did not affect spectral tilt (see Table 16 below) in the comparisons involving oral stops, mean spectral tilt results are calculated without regard to tone categorization, but are grouped by speaker and onset only. These mean spectral tilt values are plotted in Figure 6 below. Error bars indicate 95% confidence intervals here and throughout.

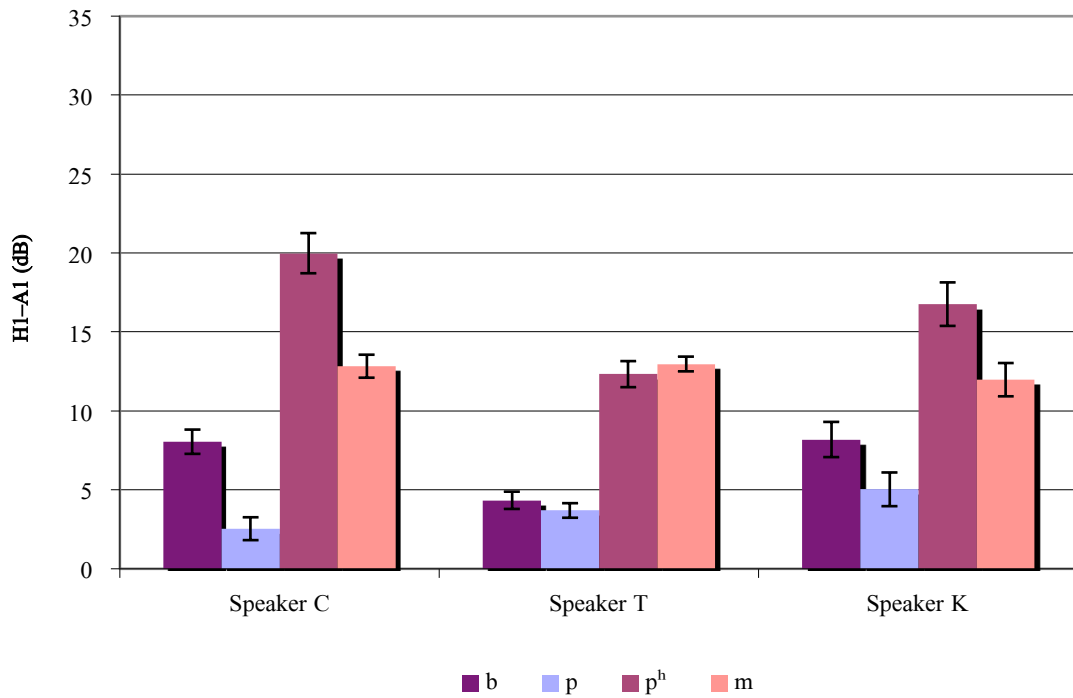


Fig. 6. Mean spectral tilt measurements for each speaker categorized by onset.

A simple analysis was performed for each onset comparison (as explained in Table 11 above). The results are shown in Table 16 for spectral tilt and in Table 18 for F0. In addition to the main effect where [b] and [p] have lower spectral tilt than [p^h] and [m], it is notable that of the three consonants, only [m] has a spectral tilt that is constant across speakers. This may be due to the fact that [m] is the only consonant that does not involve active spreading or constriction of the glottis. If this is so, it represents the H1-A1 value for modal phonation, which is constant across speakers.

Table 16

ANOVA Results for Spectral Tilt – Oral Stop Comparisons

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Comparison	Onset	Speaker	Tone	Onset*Tone	Onset*Speaker	Speaker*Tone	Onset*Tone* Speaker
[p] vs. [p ^h]	**	**	n.s.	n.s.	**	n.s.	n.s.
[p] vs. [b]	**	*	n.s.	n.s.	n.s.	n.s.	n.s.
[b] vs. [p ^h]	**	**	n.s.	n.s.	**	n.s.	n.s.
[p ^h] vs. [m]	**	**	n.s.	n.s.	**	n.s.	n.s.

In every comparison, spectral tilt measurements were significantly affected by onset. This was expected in the [p] – [p^h] and [b] – [p^h] comparisons. However, no difference was expected in the [p] – [b] and [p^h] – [m] comparisons. While both [b] and [p] were expected to be laryngealized, there was no prediction on the relative amount of laryngealization for each. Recall that the [p^h] vs. [m] comparison was included as a baseline, with the expectation that neither aspirates nor sonorants would affect F0 or spectral tilt on a following vowel. These expectations are shown to be false by the ANOVA results in Table 16 above and Table 18 below.

T-test results for specific comparisons are summarized in Table 17 below for each comparison. It is evident that H1–A1 for [p^h] is higher than [p] and [b] for all three speakers. This confirms that [p] and [b], but not [p^h], are laryngealized. In addition, two of the three speakers had significantly lower spectral tilt for [p] than for [b], indicating that a greater degree of laryngeal constriction is present in the voiceless unaspirated stop. Finally, two of three speakers also had lower spectral tilt in [m] than in [p^h], counter to the hypothesis that they would be equal. This may be indicative of some breathiness due to the aspiration in [p^h], which would raise the spectral tilt measurement relative to [m].

Table 17

T-test results for spectral tilt comparisons among oral stops

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Speaker	[p] vs. [p ^h]	[b] vs. [p]	[b] vs. [p ^h]	[p ^h] vs. [m]
C	[p] < [p ^h] **	[p] < [b] **	[b] < [p ^h] **	[m] < [p ^h] **
T	[p] < [p ^h] **	[p] < [b] n.s.	[b] < [p ^h] **	[p ^h] < [m] n.s.
K	[p] < [p ^h] **	[p] < [b] *	[b] < [p ^h] **	[m] < [p ^h] *

Unlike spectral tilt, tone did significantly affect F0. Because of this, mean F0 measurements are computed across each subject-tone-onset combination. This reduces the power of statistical analysis, but is required since the interaction of the factors significantly affects F0. Table 18 below summarizes the results for ANOVA’s run on data containing only the relevant pairs of onsets for each comparison.

Table 18

ANOVA Results for F0 – Oral Stop Comparisons

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Comparison	Onset	Speaker	Tone	Onset*Tone	Onset*Speaker	Speaker*Tone	Onset*Tone *Speaker
[p] vs. [p ^h]	**	**	**	n.s.	n.s.	**	n.s.
[p] vs. [b] ²⁴	n.s.	--	--	--	--	--	--
[b] vs. [p ^h]	**	**	**	**	n.s.	**	n.s.
[p ^h] vs. [m]	**	**	**	**	n.s.	**	n.s.

In three of the four comparisons, onset type affected F0. Significant effects were discovered in both the [p]-[p^h] and [b]-[p^h] comparisons, but not in the [p]-[b] comparison. The baseline comparison between [p^h] and [m] yielded an effect, just as it did for spectral tilt. Mean initial F0 was calculated for each speaker-tone-onset combination. Figure 7 below plots F0 means for each speaker.

²⁴ Since F0 was not affected by the onset difference in the [p] vs. [b] comparison, no further statistical testing is reported within this data.

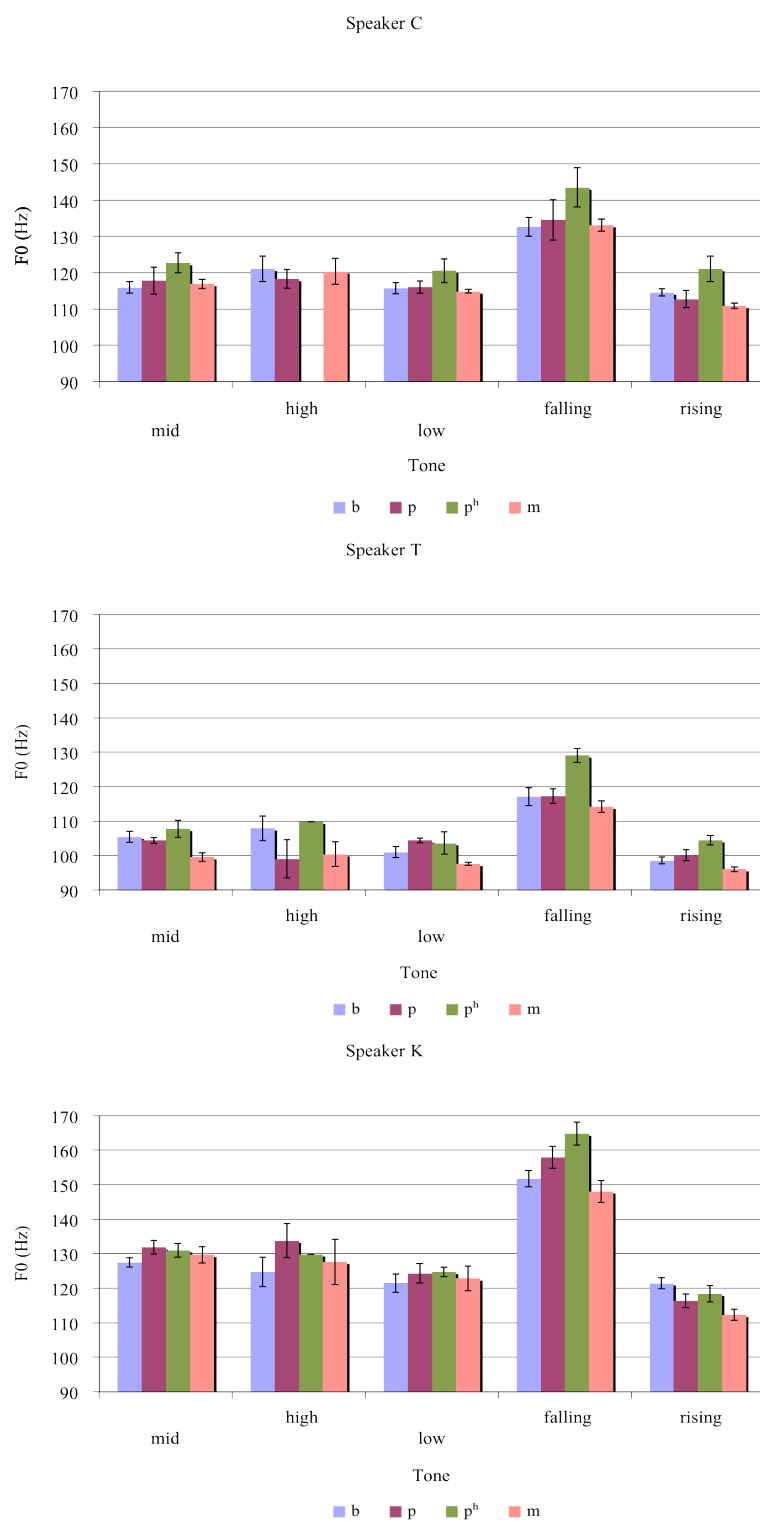


Fig. 7. Mean initial F0 measurements categorized by onset – oral stops

In comparisons between the oral stops, the only significant difference was discovered with falling tone for Speaker T, where [p^h] has higher F0 than [p], as can be seen in Figure 7. T-test results are summarized in Table 19 below for each comparison.

Table 19

T-test results for F0 comparisons among oral stops

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Speaker – Tone	[p] vs. [p ^h]	[b] vs. [p ^h]	[p ^h] vs. [m]
C – M Tone	[p] < [p ^h] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
C – H Tone	--	--	--
C – L Tone	[p] < [p ^h] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
C – F Tone	[p] < [p ^h] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
C – R Tone	[p] < [p ^h] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
T – M Tone	n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
T – H Tone	--	--	--
T – L Tone	[p ^h] < [p] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
T – F Tone	[p] < [p ^h] *	[b] < [p ^h] n.s.	[m] < [p ^h] **
T – R Tone	n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] *
K – M Tone	[p ^h] < [p] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
K – H Tone	--	--	--
K – L Tone	[p] < [p ^h] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] n.s.
K – F Tone	[p] < [p ^h] n.s.	[b] < [p ^h] n.s.	[m] < [p ^h] *
K – R Tone	[p] < [p ^h] n.s.	[p ^h] < [b] n.s.	[m] < [p ^h] n.s.

While not statistically significant, mean F0 for both [b] and [p] is lower than [p^h] for every tone for Speaker C.²⁵ The other speakers trended in this direction also, however there were some exceptions. Initial F0 is higher in [p] than [p^h] when preceding low tone for Speaker T and when preceding mid tone for Speaker K. Initial F0 is higher in [b] than [p^h] when preceding rising tone for Speaker K. In all other categories, F0 was higher for [p^h] than [b], however, indicating some weak evidence in favor of the pitch-lowering hypothesis for [p] and [b]. Unlike for spectral tilt, the results for F0 are not statistically significant on the whole though. This is not surprising in a tone language, since F0 is

²⁵ Here and throughout, t-tests within the high tone category were usually impossible due to the small amount of data available with high tone. The high error rate in high-tone tokens made it necessary to remove a large number of high-tone tokens, leaving the sample size at 1 or 0 in many cases.

involved as a major cue in creating tonal contrasts, and will thus be regulated by speakers to a greater degree. Spectral tilt, on the other hand, is not involved in contrasts in Thai, and so coarticulatory effects are more readily observed.

Notably, in the comparison between [p^h] and [m], three of the fifteen comparisons were significant. Speakers T and K had higher F0 following [p^h] than [m] on falling tone. Speaker T also had higher F0 following [p^h] than [m] in rising tone. In fact, even in the insignificant comparisons, F0 is always higher following a [p^h] onset, than it is following an [m] onset. Inspection of Figure 7 shows that [m] even has lower mean F0 values than [b] and [p] in some cases, suggesting that [m] is actively lowering F0 also.

In conclusion, there is strong evidence from spectral tilt measurements and weak evidence from F0 measurements that [b] and [p] are laryngealized, suggesting that they share the common phonological feature value [+constricted glottis]. Spectral tilt measurements were significantly different in all comparisons involving the oral stops. [p] had the lowest spectral tilt, followed by [b], and then by [p^h], which had the highest spectral tilt. The finding that [p] has lower spectral tilt than [b] indicates that [p] has a greater degree of laryngealization than [b]. F0 results were less definitive. While there was a noticeable trend in the direction expected (F0 is lower following [p] and [b] than it is following [p^h]), this trend only reached statistical significance in 1 out of 30 speaker-tone-onset categories. Interestingly, the comparisons between [p^h] and [m] suggest that [m] involves active pitch lowering, relative to [p^h].

3.3.2 *The Glottals: ʔ and h*

While the main focus of this chapter was to show that unaspirated and voiced

obstruents are laryngealized, the glottal stop [ʔ] and glottal fricative [h] both involve laryngeal features as well. Phonologically, [ʔ] and [h] do not occur preceding high tone in unchecked syllables, just like the unaspirated and voiced obstruents. For [ʔ], recall there are two hypotheses. The first hypothesis is that there should be lowered spectral tilt and lowered F0 measurements following [ʔ], just like [p] and [b]. This is the case if the phonetics mirrors the phonology and [+constricted glottis] is articulated with creaky laryngeal constriction. The second hypothesis is that [ʔ] is produced with harsh laryngeal constriction, thus raising F0. The results support the second hypothesis: F0 (and spectral tilt) immediately following [ʔ] is significantly higher than following [p].

Turning to the glottal fricative [h], recall that it does not occur preceding high tone, while the aspirated stops do. This was thought to indicate a phonological difference between [h] and the aspirated stops with respect to the feature [slack]: While [h] is [+slack], the aspirated stops are [−slack]. The specific prediction was that [h] should correlate with lowered F0 and raised H1–A1, relative to [p^h]. A comparison between the acoustic characteristics of [p^h] and [h] confirmed that [h] raises spectral tilt to a greater degree than [p^h] but no difference in F0 was discovered, counter to expectations. However, the spectral tilt result supports the conclusion that [h] is [+slack] and [p^h] is not.

Unlike the oral stops in the previous section, [ʔ] is associated with a relatively high spectral tilt. Spectral tilt is significantly higher following [ʔ] than [p] ($p < 0.001$ in t-tests all five tones), as can be seen in Figure 8 below. The mean spectral tilts are calculated across the three speakers since a simple analysis showed that there was no effect on spectral tilt for speaker in the [ʔ] vs. [p] comparison.

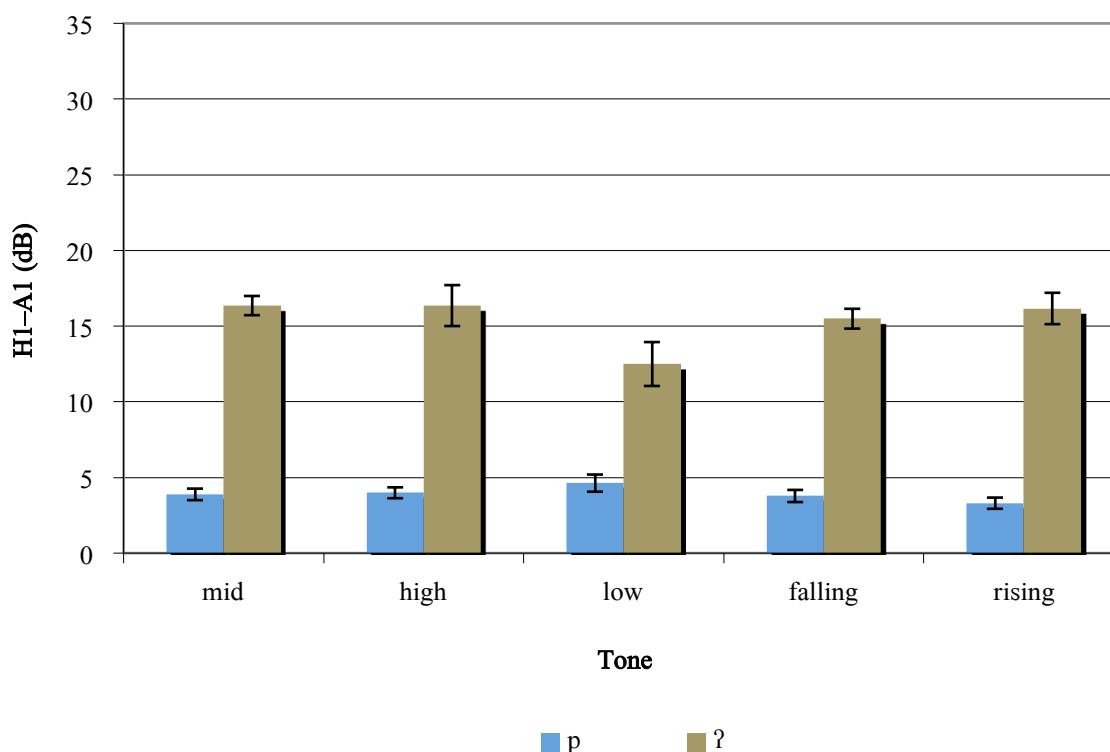


Fig. 8. Mean spectral tilt across speakers – [p] vs. [ʔ]

The high spectral tilt values for [ʔ] indicate that it is not inducing creakiness, unlike [p], which is inducing creakiness, as outlined in Section 3.3.1. Therefore, while [ʔ] may pattern with [p] phonologically, the laryngeal articulations of [ʔ] and [p] are phonetically distinct. Comparisons of initial F0 for [ʔ] and [p] confirm this conclusion as F0 following [ʔ] is consistently higher than [p], in all categories. This result is consistent with the hypothesis that [ʔ] in Thai is actually produced with harsh laryngeal constriction. Figure 9 below summarizes the results for Speaker T. F0 means are calculated for each speaker and for each tone, since both independent factors significantly affected F0.

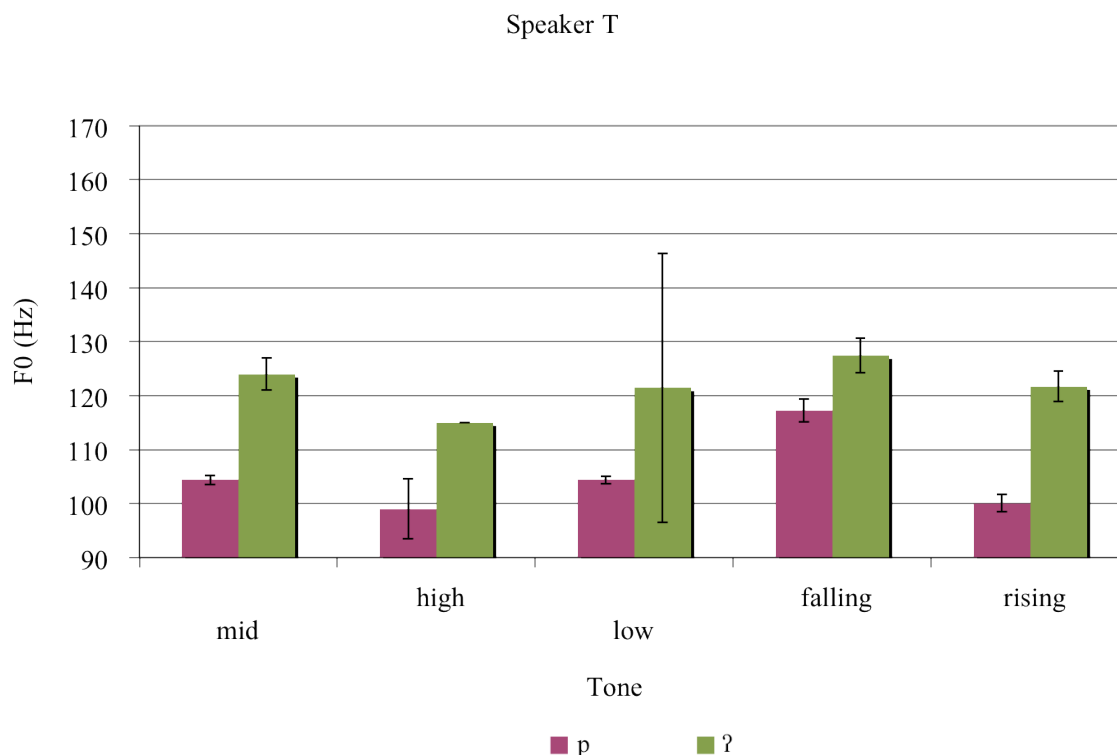


Fig. 9. Mean F0 – [p] vs. [ʔ] for Speaker T

Table 20 summarizes t-test results. While F0 differences reach statistical significance in only two of fifteen speaker-tone categories (for Speaker T with mid and rising tone), the consistency of the direction of the effect suggests that [ʔ] correlates with higher F0 compared to [p].

Table 20

T-test results for F0 comparisons between [p] and [ʔ]

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Tone	Speaker C	Speaker T	Speaker K
Mid	[p] < [ʔ] ^{n.s.}	[p] < [ʔ] **	[p] < [ʔ] ^{n.s.}
High	[p] < [ʔ] ^{n.s.}	--	[p] < [ʔ] ^{n.s.}
Low	[p] < [ʔ] ^{n.s.}	[p] < [ʔ] ^{n.s.}	[p] < [ʔ] ^{n.s.}
Falling	[p] < [ʔ] ^{n.s.}	[p] < [ʔ] ^{n.s.}	[p] < [ʔ] ^{n.s.}
Rising	[p] < [ʔ] ^{n.s.}	[p] < [ʔ] **	[p] < [ʔ] ^{n.s.}

Turning now to the comparison between the two glottals, [ʔ] and [h], Figure 10

summarizes mean spectral tilt values for [ʔ] and [h] onsets, categorized by onset and tone, across speakers. [ʔ] has been established as harsh and not creaky, but it is unclear what effect harsh phonation has on spectral tilt. Figure 10 shows that mean spectral tilt for [h] is higher than [ʔ]. It is expected that [h] would have a relatively high spectral tilt, due to increased breathiness. The relatively moderate spectral tilt values for [ʔ] suggest that harsh laryngeal constriction has a relatively small effect on spectral tilt. The H1–A1 values are not very different from those for modal phonation (cf. Figure 6 above).

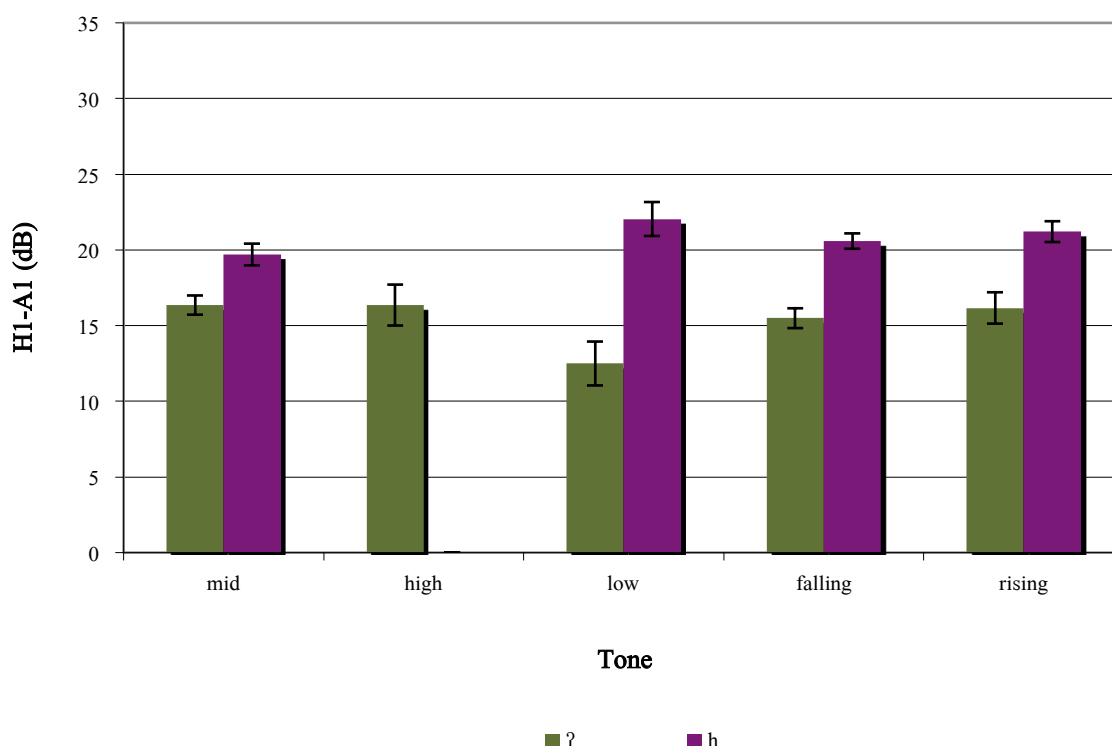


Fig. 10. Mean spectral tilt – [ʔ] vs. [h] across speakers

Table 21 below shows that higher mean spectral tilt is seen following [h] than [ʔ] with low tone, for all three speakers. The remaining two significant differences also involved higher spectral tilt for [h] than [ʔ]: Speaker K has higher spectral tilt following

[h] with mid tone and Speaker C has higher spectral tilt following [h] with rising tone.

While the other comparisons did not yield significant results, [h] has higher spectral tilt than [ʔ] in nine out of twelve cases.

Table 21

T-test results for spectral tilt comparisons between [ʔ] and [h]

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Tone	Speaker C	Speaker T	Speaker K
Mid	[ʔ] < [h] ^{n.s.}	[h] < [ʔ] ^{n.s.}	[ʔ] < [h] *
High	--	--	--
Low	[ʔ] < [h] **	[ʔ] < [h] *	[ʔ] < [h] **
Falling	[ʔ] < [h] ^{n.s.}	[h] < [ʔ] ^{n.s.}	[ʔ] < [h] ^{n.s.}
Rising	[ʔ] < [h] *	[h] < [ʔ] ^{n.s.}	[ʔ] < [h] ^{n.s.}

The F0 results show a divergence from the spectral tilt results, however. [ʔ] is associated with a slightly higher mean F0 than [h], as shown for speaker K in Figure 11 below.

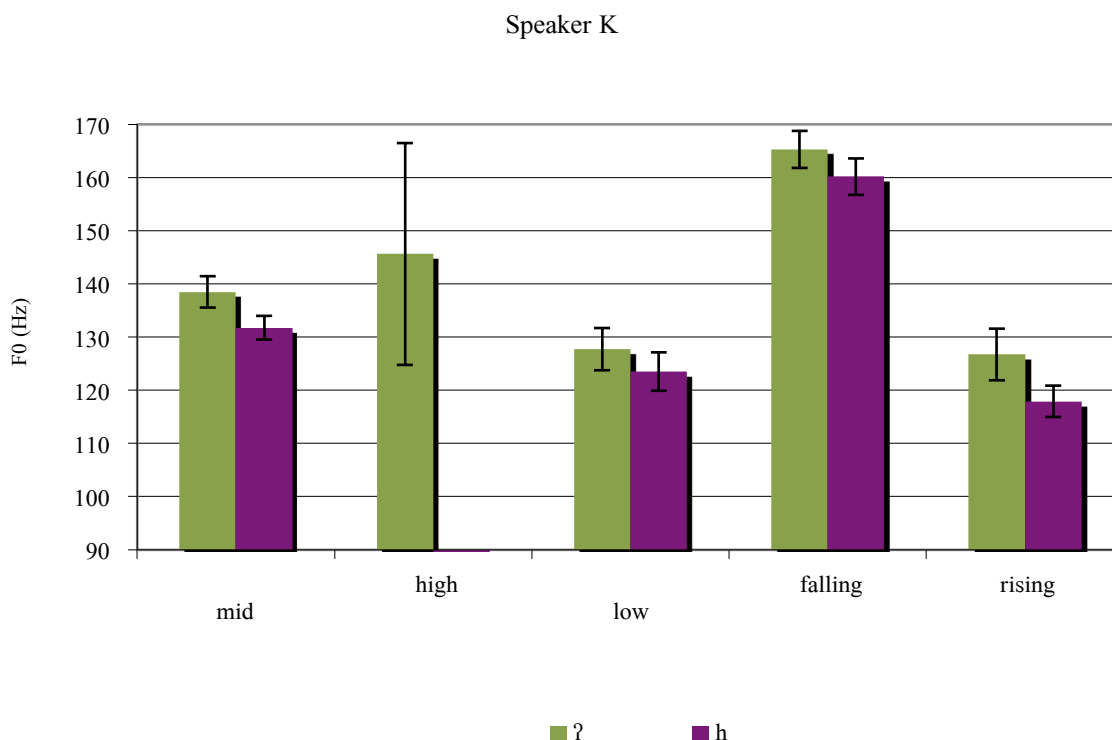


Fig. 11. Mean F0 – [?] vs. [h] for Speaker K

Only a single significant difference was found in Table 22 however: Speaker T has significantly higher F0 for [?] than [h] in rising tone. While not significant, mean F0's following [?] are higher than mean F0's following [h] in all but two of the t-test comparisons in Table 22 below. Just as was seen in the comparison with [p], [?] is associated with raised F0 in Thai then, a finding consistent with harsh laryngeal constriction.

Table 22

T-test results for F0 comparisons between [?] and [h]

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Tone	Speaker C	Speaker T	Speaker K
Mid	[h] < [?] n.s.	[h] < [?] n.s.	[h] < [?] n.s.
High	--	--	--
Low	[h] < [?] n.s.	[h] < [?] n.s.	[h] < [?] n.s.
Falling	[?] < [h] n.s.	[?] < [h] n.s.	[h] < [?] n.s.
Rising	[h] < [?] n.s.	[h] < [?] *	[h] < [?] n.s.

The final comparison involves [h] and [p^h], where only spectral tilt, and not F0, was significantly affected by onset. Mean spectral tilt is plotted categorized by speaker and onset in Figure 12 below. Results for t-tests are summarized in Table 23.

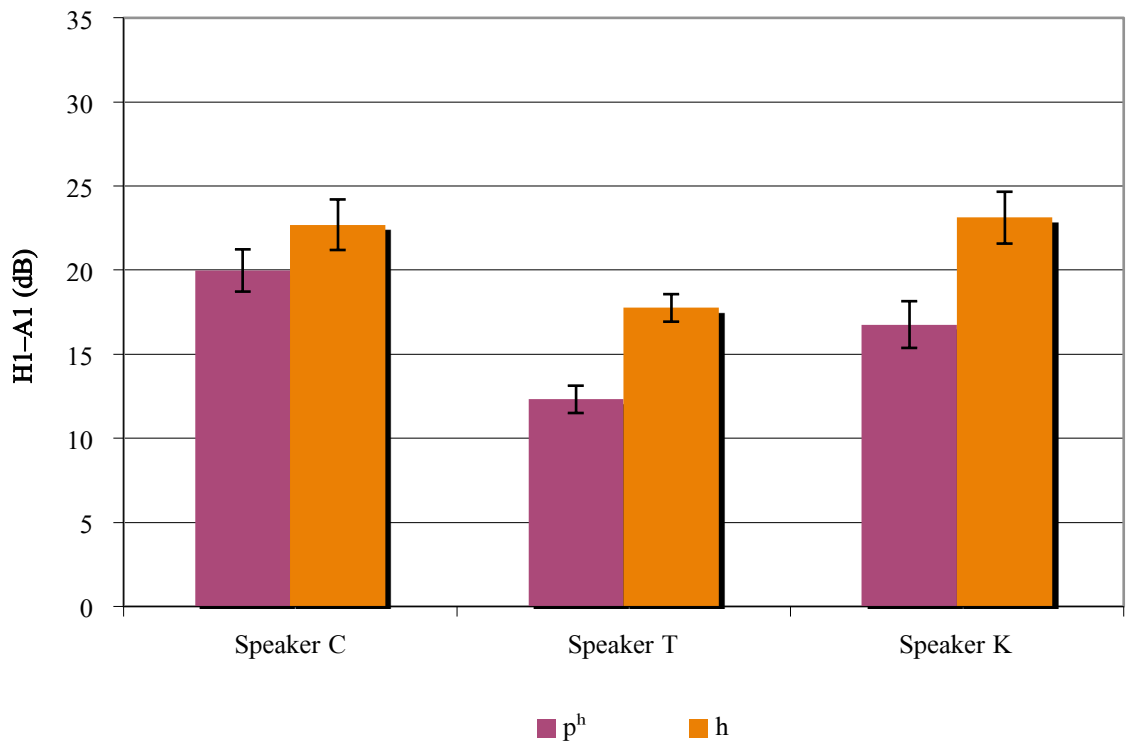


Fig. 12. Mean Spectral Tilt – [h] vs. [p^h]

Table 23

T-test results for spectral tilt comparisons between [h] and [p^h]

(** = $p < 0.001$; * = $p < 0.05/n_i$ (bonferonni adjusted); n.s. = “not significant”)

Speaker	[h] vs. [p ^h]
C	[p ^h] < [h] n.s.
T	[p ^h] < [h] **
K	[p ^h] < [h] **

Figure 12 shows that [h] has higher spectral tilt than [p^h] for all three speakers but as Table 23 shows, this is only significant for Speakers T and K. This result suggests a

greater degree of breathiness in [h] than in [p^h], consistent with [h] being [+slack], but not [p^h].

In conclusion, [ʔ] was found to have significantly higher spectral tilt than [p]. Additionally, [ʔ] was found to *raise* F0, while [p] lowers F0. These findings indicate that [ʔ] is articulated with a harsh laryngeal constriction, unlike [p] and [b], which are accompanied with creaky laryngeal constriction. Finally, [h] was found to have higher spectral tilt than [p^h], while no difference in F0 was discovered. This indicates that [h] has a higher degree of breathiness than [p^h], as expected if it is [+slack] and [p^h] is not.

3.3.3 Conclusion

In summary, F0 and spectral tilt measurements both suggested that [b] and [p], but not [p^h] are laryngealized. Furthermore, spectral tilt results suggested that [p] has a greater degree of laryngeal constriction than [b]. While the laryngealized stops [b] and [p] pattern with [ʔ] phonologically, [ʔ] is not laryngealized in the same manner as [b] and [p]: [ʔ] induces very high spectral tilt and F0 at the onset of a following vowel in contrast with [b] and [p], which induce very low F0 and spectral tilt. These results confirm that [ʔ] is articulated with a harsh laryngeal constriction, and [b] and [p] are articulated with a creaky laryngeal constriction. This implies that the phonology is generalizing across different phonetic articulations for laryngealization in a restriction that bans high tone following [b], [p], and [ʔ] in unchecked syllables. Finally, the phonological ban on [h] preceding high tone in unchecked syllables may be explained by the fact that [h] has higher spectral tilt, and is therefore relatively more breathy than aspirated stops in Thai. [h] is distinguished from other segments by virtue of being [+slack], an articulation that

results in increased breathiness. A phonological ban exists in Thai, where high tone is banned following [+slack] onsets then.

3.4 Discussion and Concluding Remarks

Among the results summarized in Section 3.3, the findings for the glottal sounds warrant further discussion. First, the nature of [ʔ] in Thai is discussed in Section 3.4.1. The fact that [ʔ] has higher spectral tilt and F0 than [b] and [p] indicates that [ʔ] is articulated distinctly from [b] and [p]. However, [ʔ], [b], and [p] form a single phonological class: All three sounds involve laryngeal constrictions and are banned preceding high tones. Second, the results for [h] highlight that a separate feature ([+slack]) is also banned with high tone in Thai. In addition, it is apparent that spectral tilt results appear to provide a “higher resolution” than F0: Where large differences in spectral tilt are found immediately following the onset consonants in question, only small, often insignificant, differences in F0 are found. This observation is expected in tone languages, where F0, but not spectral tilt, is regulated by speakers since it is involved as a primary cue in tone contrasts. Finally, this section closes with a discussion about what the acoustic results mean for phonological accounts of consonant-tone interaction in Thai, which provided the motivation for the study in the first place. The main finding, that unaspirated and voiced obstruent onsets in Thai are laryngealized suggests that a phonological analysis of onset-tone interaction involves the feature value [+constricted glottis].

3.4.1 Glottal Stop – A Different Mode of Laryngealization

Interestingly, [ʔ] showed F0-raising effects as well as relatively high spectral tilt. Inspection of the glottal stops produced by the three speakers showed that, in fact there was little or no creak associated with them. Instead, a clear stop release can be seen in the spectrogram in Figure 13 below. Importantly, there aren't any irregular glottal pulses indicative of creakiness.²⁶

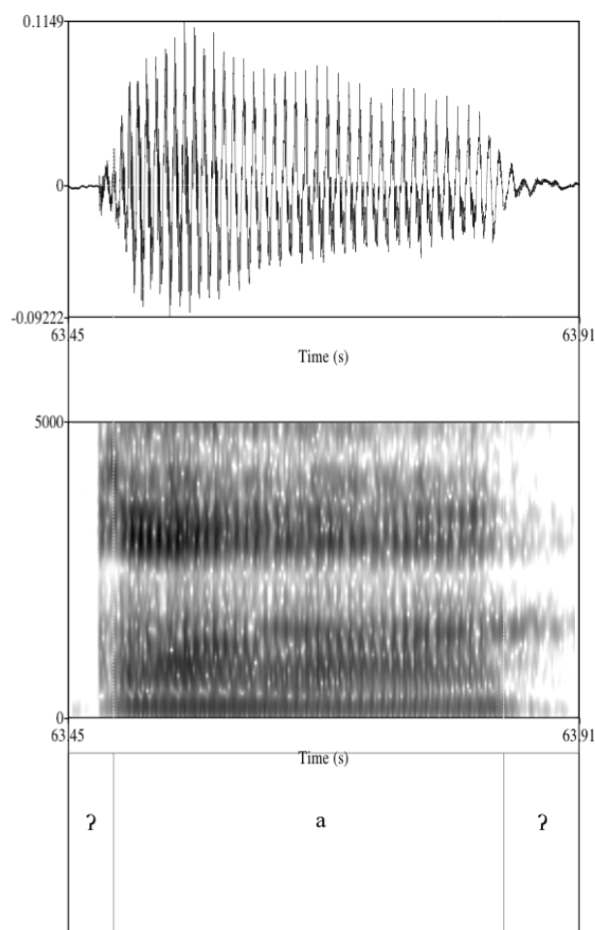


Fig. 13. Glottal Stop Onsets

²⁶ The ? onset contrasts with the final ?, which is not articulated with a sharp glottal release, but is instead articulated with creakiness over its duration.

The spectrogram in Figure 13 has a sharp vertical boundary at the onset of the word, indicating the release of the glottal stop. [ʔ] in Thai is not associated with creakiness, but is rather associated with a glottal closure and release. This is compatible with the results where F0 and spectral tilt are higher for [ʔ] than [p]. Furthermore, the spectral tilt and F0 results indicate that [p] is articulated with creakiness in the following vowel, but [ʔ] is articulated with harsh laryngeal constriction. Esling & Harris (2005) and Edmondson & Esling (2006) describe two modes of laryngealized voicing: creaky voice, which they note, is associated with lower F0, and what they describe as harsh voice, which is associated with higher F0. They further note that harsh voice is typically associated with constriction of the ventricular folds (located above the vocal folds), an articulation that is common in glottal stops. This suggests that Thai glottal stops employ an articulation that results in harsh voice rather than creaky voice.

This finding suggests that glottal stops may vary in their phonetic production cross-linguistically. Notably, languages do not seem to contrast these phonetically different glottal stops; therefore, the variation seen in glottal stops may only have a larger role to play in phonetic theories of coarticulation and in diachronic changes involving tonogenesis (e.g. Kingston 2005). Phonologically, the evidence from onset-tone interaction in Thai points to a more simplified set of features ([constricted glottis], [spread glottis], [stiff], [slack]), consistent with traditional analyses of laryngeal features (e.g. Halle & Stevens 1971; Bao 1990).

3.4.2 *Glottal Fricative – Evidence for Resolution Differences in F0 and Spectral Tilt*

A third interesting observation concerns the comparison between [h] and [p^h], which

was made with the phonological high-tone restriction involving [h] onsets in mind. The ban on [h], but not [p^h] preceding high tone is explained by the fact that [h] is [+slack], whereas [p^h] is not. Evidence for this was discovered in that [h] had higher spectral tilt than [p^h]. This confirms the presence of a ban against [+slack]-high tone sequences in Thai. Notably, the evidence for this ban came mostly from spectral tilt results, and not F0 results. Breathiness normally lowers F0, but the F0 measurements for [h] and [p^h] were not significantly different. A similar finding where spectral tilt measurements revealed finer-grained distinctions was found with [b] and [p]. While no difference was discovered between the F0 measurements, [p] was found to have lower spectral tilt than [b]. The resolution of the spectral tilt comparisons is finer than the F0 comparisons then.

This difference in resolution has a principled explanation. 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). They suggest that this effect can be explained since in tone languages, F0 is a primary indicator of lexical contrast, whereas in non-tone languages, it is not. Therefore, speakers of tone languages actively minimize the phonetic effects that consonants have on F0. Kingston & Diehl (1994) note that speakers can actively control phonetic details in this manner. If this is the case in Thai (as Gandour 1974b suggests it is), then the fact that F0 effects are less significant than spectral tilt is unsurprising. Spectral tilt is not involved (directly) as a cue in any contrast in Thai, and so it is not controlled to the same extent as F0. As such, it is a better indicator of contextual laryngealization than F0 in a tone language such as Thai, where F0 is the primary cue for tonal contrasts.

3.4.3 *Implications for Phonology*

The main finding of the acoustic study is that voiced and voiceless unaspirated obstruent onsets are laryngealized in Thai. A phonological account of onset-high tone restrictions that refers directly to these phonetic findings can capitalize on this. Previous accounts that used the feature specification [–spread glottis] (Ruangjaroon 2006; Lee 2008) did so in order to group the voiced and voiceless unaspirated obstruents in a single class. This analysis is inconsistent with usual assumptions that [spread glottis] and [constricted glottis] are privative features (Lombardi 1991:27; Clements and Hume 1995:270; Kehrein 2002:66; Hall 2007:317-318). Instead, the results summarized in Section 3.3 showed that voiced and unaspirated obstruents are laryngealized phonetically. Therefore, [+constricted glottis] is the active phonological feature value in onset-tone interaction in Thai, rather than [–spread glottis]. This analysis is consistent with both the phonetic results and the privativity of the features [spread glottis] and [constricted glottis].

Using the feature [+constricted glottis], [ʔ], [b], and [p] can be treated as a single natural class. The glottal stop [ʔ] patterns with the laryngealized obstruents in that it too is banned preceding high tone in unchecked syllables. However, this acoustic study has highlighted the fact that this phonological grouping conflates two distinct phonetic categories of laryngealization: The voiced and unaspirated obstruents induce creaky voice (lowering F0) while ʔ induces harsh voice (raising F0) in a following vowel. Notably, this difference is not involved in creating contrast, and so the phonology involves a generalization across the actual details of the laryngeal articulations, focusing on the coarser-grained distinction between whether sounds involve laryngeal constriction of any

kind (i.e. [ʔ, p, b]) or not (i.e. [p^h]). Therefore, treating [ʔ] as [+constricted glottis], on par with [b] and [p], simplifies the phonological system, at the cost of introducing a phonetically unnatural consonant-tone restriction: [ʔ] raises F0 and spectral tilt, but is banned preceding high tone.

This chapter has reported results of an acoustic experiment, confirming that unaspirated and voiced obstruents in Thai involve laryngeal constriction. The onset-tone restricting constraint that is hypothetically active in the Thai grammar therefore involves the feature [+constricted glottis], and not the feature [–spread glottis] as proposed by Lee (2008) and Ruangjaroon (2006). The following chapter assesses the psychological reality of this constraint via a forced choice judgment task.

Chapter 4 – Onset-Tone Interaction in Thai: A Perceptual Experiment

4.1 Introduction

This chapter consists of two experiments that address the grammatical status of the onset-tone lexical gaps outlined in Chapter 2. Four gaps were identified in unchecked syllables, although the results from Chapter 3 reduce this to two gaps: [+constricted glottis] onsets do not co-occur with high tone or rising tone within a syllable.

Acceptability judgments are elicited from native Thai speakers in order to assess whether the lexical gaps are grammaticalized. The experiment tests whether a markedness constraint banning high and rising tone with [+CG] (both voiced and unaspirated) onset consonants exists in Thai. A second major goal of this chapter is to establish whether there is a difference in the grammatical restrictions between an English loan stratum and the native stratum of Thai. Recall from Chapter 2 that the lexical gaps involving high tone held in the native stratum, but not in the loan stratum. In Experiment 1, the task instructions encourage participants to treat the stimuli as loans; on the other hand, in Experiment 2, the task instructions encourage participants to treat the stimuli as native items. Taken together, the experiments will assess whether there is a distinction in the grammaticality of onset-tone sequences for native items and English loan words in the Thai grammar.

The following subsections constitute an overview of theoretical and methodological issues that such an experiment faces, in order to assess an optimal experimental design. First, acceptability judgments do not necessarily address grammaticality, but can also be affected by lexical frequency knowledge. Lexical Neighborhood Density is calculated for each stimulus to control for this potential effect. Second, there are a range of possible

task types used in eliciting acceptability judgments, but among these, it is argued that a forced-choice task, where participants choose between two options, is superior to other task types for studies where there is a possibility of gradient grammaticality distinctions, such as the current experiment. This task will also have implications for theories of markedness in consonant-tone interaction since participants will essentially be assessing the relative markedness of the stimuli.

4.1.1 Lexical Frequency Effects on Acceptability Judgments

A basic assumption of this and other similar judgment experiments is that acceptability judgments reflect grammatical knowledge. However, actual acceptability judgments reflect more than just grammaticality. Knowledge of frequency in the lexicon affects acceptability judgments, for example (Newman et al. 1997; Coleman & Pierrehumbert 1997; Vitevitch & Luce 1998, 1999; Bailey & Hahn 2001; Frisch et al. 2000, Shademan 2007). Bailey & Hahn (2001) elicited wordlikeness judgments of nonwords from English speakers, finding that while both lexical frequency and phonotactics contributed independently, lexical neighbourhood density (LND) explained their experimental results better than phonotactics (cf. Shademan 2007, where the reverse is discovered, that phonotactics has a larger effect than lexical frequency). However, a large portion of the variance in Bailey & Hahn's results was unaccounted for by either phonotactics or LND, suggesting that other unknown factors contribute to wordlikeness judgments. In constructing experimental stimuli, Bailey & Hahn tested both orthographic and auditory stimuli and concluded that there was no difference in the effects on wordlikeness judgments in their experiments.

Since acceptability judgments can reflect lexical knowledge in addition to grammatical knowledge, it is important to control for lexical effects. Vitevitch & Luce (1998, 1999) showed that details of the experiment design determined the degree to which participants applied lexical knowledge or grammatical knowledge. They found that when they used actual English words as stimuli testing for acceptability of certain phonotactic sequences, LND correlated with judgments to a greater degree than phonotactic probability (i.e. grammaticality). This suggests that nonce stimuli are preferable in an experiment that is testing for grammaticality, in order to minimize lexical frequency effects.

It is assumed here that acceptability judgments are affected only by lexical knowledge and grammatical knowledge. As a result, it is expected that once any effects of lexical knowledge on an acceptability judgment are removed, any remaining effects are indicative of grammatical knowledge. The strategy of the two experiments here is to account for any lexical frequency effects, attributing any remaining effect to grammaticality.

As a way to measure lexical effects, the LND's for the experimental stimuli are calculated based on corpus frequencies from the ORCHID corpus (Kasuriya et al. 2003). The LND is then included as a factor in a logistic regression model to test whether it significantly affects participants' responses. In calculating LND, lexical neighbors were defined based on single phoneme addition, subtraction, or substitution, following Vitevitch & Luce (1998, 1999). A script, written in Ruby, translated the orthographic Thai corpus into both IPA, and a modified form of IPA, in which exactly one character is used per meaningful phoneme unit, in order to make the analysis of the translated corpus

a more straightforward task. The Ruby script is included in Appendix B. The following subsection provides a brief introduction to the strategies employed in the script.

4.1.2 *Translating Thai Orthography to IPA*

The Ruby script used to translate the ORCHID corpus to IPA identifies characters and character sequences that uniquely correspond to phones. It then assigns that phone to its corresponding syllable position in an object corresponding to the phonetic form. In many cases, a single character can correspond to a number of different phones, depending on the context. This subsection presents a short example of one such case to illustrate the strategy used to disambiguate these. (10) below illustrates the general orthographic template for a Thai syllable.

(10) Thai Orthographic Template for Syllables

$$(V_1)\text{-}C_{\text{ons1}}\text{-(}C_{\text{ons2}}\text{)}\text{-(}^{(V_2)}\text{-(Tone)}\text{)-}V_3\text{-(}C_{\text{coda}}\text{)}$$

The template consists of seven distinct character slots. The only obligatory elements in an orthographic syllable are an onset character and a vowel character (V_3). Some Thai vowels require an additional vowel-marking character preceding the onset consonant (V_1) and/or a diacritic following the onset (V_2). Sometimes, phonetic tones are marked explicitly as diacritics following the onset consonant; in the absence of a tone diacritic character, phonetic tone is determined contextually based on the onset consonant character. A nonce example with all seven slots filled is given in (11) below.

(11) An example Thai (nonce) syllable

ไพ๋ยน [p^hriâ:n]

ไ๋ย [ia:] vowel (x marks the onset position)

พริ [p^hr] cluster

ั falling tone (where x is a low-class consonant, like ฃ)

น [n] coda

One example of a particular challenge in translating Thai text to IPA concerns ambiguities where some Thai characters can occur in more than one possible syllable slot. For example, the character “ร” is pronounced as [w] when it appears in onset or coda position. However, it also appears in the V₃ slot to denote the diphthong [ua]. In open syllables with [ua], “ร” follows a diacritic vowel character: ัร²⁷. In closed syllables, the diacritic is absent. In addition, the diacritic character, ั, also denotes the vowel [a], but only in closed syllables.

As a result of this set of facts, it is possible to predict the role of “ร”, based on the surrounding context. Whenever “ร” immediately follows the vowel diacritic, ั, (allowing for a possible intervening tone diacritic character) it is guaranteed to be in its [ua] vowel guise. The strategy here is to show that “ร” cannot be an onset or a coda when it follows ั, meaning it must be in its [ua] vowel guise. The only other time we see ั marking a

²⁷ The character “อ” is used here as a dummy consonant. It denotes a glottal stop onset.

vowel in Thai is the short [a] vowel. First, this vowel character is only used for closed syllables, meaning that a following “๐” must not be an onset, it can only be a coda.

However, in Thai, [aw] rimes involve an idiomatic orthographic sequence: ๑๐๑. This sequence is the only way to orthographically represent the [aw] rime. Therefore, if it cannot be an onset or coda, “๐” is unambiguously in its vowel guise whenever it follows the ๑ vowel diacritic (with an optional intervening tone mark). In the Ruby script, the use of regular expressions enables context-sensitive searches for ambiguous characters like “๐”. Some other general disambiguating contexts involve the following:

1. A character with a tone or vowel diacritic over it must be an onset consonant.
2. A character immediately following a tone or vowel diacritic must be a vowel in V3 position.
3. An unambiguous consonant character preceding one of the unique vowel prefixes (V1) can only be a coda.

In monosyllabic words, it is possible to completely determine phonetic form from the Thai orthography. The only case of genuine ambiguity arises in multisyllabic words with certain sequences of intervocalic consonants, (...VCCV...). If the sequence is one that is a possible onset cluster, then it is ambiguous whether the first consonant in the sequence is a coda in the previous syllable or whether it is part of an onset cluster in the second syllable. For example, in a [p^{hr}] “๑๐๑” cluster, the two consonants may be separated by a syllable boundary [...Vp.rV...], or they may be part of the same syllable [...V.p^{hr}V...]. This ambiguity does not affect monosyllabic words though, and since the experiment

here uses monosyllabic stimuli, there is no harm in misparsing these intervocalic consonant sequences. The Ruby script assumes all cases such as these are consonant clusters.

By identifying and referring to “disambiguating” sequences involving such characters in the manner described here, it is possible to determine the phonetic transcription for a given string of Thai orthographic characters. The output of the script was a document that listed each word from the ORCHID corpus in IPA.

4.1.3 Task Effects on Acceptability Judgments

In addition to the lexical effects dealt with in the previous two subsections, the task type used can also influence acceptability judgments. There are a number of tasks that are commonly employed in judgment experiments, including lexical decision, identification, and discrimination tasks; however this section focuses on two particular tasks. The first task type asks participants to rate a stimulus on a numerical acceptability scale (rating-based task). The second asks participants to choose which of two stimuli is more acceptable (forced-choice task). Notably, both task types allow for gradient acceptability judgments, but the forced-choice task has proven superior in its ability to identify finer-grained acceptability judgments.

While gradient acceptability may indicate an interaction between grammaticality and lexical knowledge, it is also possible that grammaticality itself can be gradient rather than categorical. Evidence for phonological grammar as an internal cognitive system (Chomsky & Halle 1968) has traditionally manifested in a difference between impossible and possible sound sequences. Rule-based, and later Optimality-theoretic accounts

(Prince & Smolensky 1993/2004) provided models of these phonological grammars by separating the grammatical from the ungrammatical. However, recent experimental studies on phonological judgments in a variety of languages have shown that grammaticality can be gradient in nature (Greenberg & Jenkins 1964; Coleman & Pierrehumbert 1997; Vitevitch et al. 1997; Frisch, Large and Pisoni 2000; Bailey & Hahn 2001; Albright & Hayes 2003; Hay, Pierrehumbert & Beckman 2003; Hammond 2004; Shademan 2007; Goldrick 2011).

The forced-choice task is often found to be superior to rating-based tasks, especially in cases where grammaticality is gradient. Coetzee (2008, 2009) gives evidence that forced-choice comparison tasks and lexical decision tasks are superior to rating-based tasks in their ability to identify fine-grained grammaticality distinctions. While rating-based tasks reliably identify between grammatical and ungrammatical forms, they sometimes miss differences between grammatical forms or between ungrammatical forms. Coetzee elicited wordlikeness judgments from English speakers on nonce words of the form [spVp] and [skVk] (both unattested) and [stVt] (attested). Wordlikeness ratings were higher for [stVt] than for [spVp] and [skVk], but no difference was discovered between [spVp] and [skVk]. However, there is evidence that there is a well-formedness difference between [spVp] and [skVk]: English allows words like “skag” but not “spab”, as well as words like “skulk” but not “spulp”. While wordlikeness ratings did not reflect any such grammaticality difference, forced choice comparison and lexical decision tasks did.

Berent & Shimron (1997) found a similar task difference when comparing two licit forms in Hebrew. Forced-choice comparison of nonwords with root-final geminates

(grammatical in Hebrew) with nonwords without geminates yielded a preference for the non-geminates. However, rating-based judgments yielded no preference between these two nonword types. Therefore, speakers exhibit gradient judgments between grammatical nonwords and between ungrammatical nonwords in forced-choice comparisons. Rating-based tasks did not reveal these subtle differences in grammaticality however, suggesting that forced-choice comparison is superior to rating-based judgments in revealing subtle grammatical knowledge.

The current study on onset-tone interaction in Thai involves lexical gaps where a three-way distinction was made between unattested, under-represented, and attested forms. Taking the null hypothesis that the gradient nature of the lexical gaps are reflected as gradient differences in grammaticality, a forced-choice format is adopted in the onset-tone experiment in Thai. Additionally, theories of consonant-tone interaction like Lee's (2008) assume the presence of certain markedness constraints (*CG-H, *SG-L). Given Berent & Shimron's (1997) finding that an OCP-place constraint is applied even in comparisons among ungrammatical stimuli, we might expect the same to be seen in Thai with respect to onset-tone restrictions. For example, in comparisons between grammatical onset-tone sequences, these markedness constraints might influence judgments. A stimulus with a *voiced stop-low tone* sequence may be preferable to a stimulus with an *aspirated stop-low tone* sequence for example, because of the affinity for voicing and low tone (Halle & Stevens 1971; Bradshaw 1998; Lee 2008; Tang 2008).

4.1.4 Effects of Lexical Stratum

In Chapter 2, it was apparent that different generalizations hold among native Thai words and English loan words. A number of studies have shown that experimental stimuli are judged differently depending on which lexical stratum they belong to. Gelbart (2005) and Moreton & Amano (1999) showed that perceptual boundaries along a continuum were affected by stratal lexicon membership in Japanese. Gelbart used real words that both contained only native sounds, but one sound in the stimuli was one featural change away from a non-word that would violate a phonotactic constraint in only one of two Japanese lexical strata. Continua varying consonant length (geminate *dd*, *bb*, and *gg* at one endpoint, with singletons *d*, *b* and *g* at the other endpoint) and word-final vowel length (*a~a:*) were used. Geminates and word-final long vowels are banned in non-foreign strata, but are allowed in foreign strata. Participants were asked to judge if the target segment was long or short. In non-foreign stimuli, participants' boundaries were shifted towards the short vowels and singleton consonants, implying the knowledge of lexical stratum membership affects their perception of the vowel length. Gelbart's findings stress that the effect of lexical stratum membership is independent of effects of phonotactic transitional probability or lexical neighborhood density.

While Gelbart used real word stimuli, nonce stimuli are used in Experiments 1 and 2, introducing some potential ambiguity in terms of lexical stratum classification. Moreton & Amano (1999) explored lexical stratum effects in Japanese with nonce stimuli in a similar manner to Gelbart. In one experiment, they use real word stimuli, manipulating final vowel length, just as Gelbart did. In a second experiment, they use CoC'a-shaped nonce words. By using consonants only present in one stratum, they cued participants to

interpret the nonce stimuli as belonging to a particular stratum. Their results show a stronger boundary shift in the second experiment: Participants were biased towards hearing a long vowel in nonce words with foreign cues, and this effect was stronger than it was with the real word stimuli in Experiment 1. This implies not only that lexical strata interact with grammar, but also that classification of lexical stratum of a nonce stimulus can be influenced by phonotactic cues in the stimulus.

The way in which lexical strata relate is not random. Ito & Mester (1995, 1999, 2001) found that languages in which distinct lexical strata exist are structured with a core native grammar, and successively more permissive loan and peripheral grammars. An implicational relationship exists, where if a given restriction holds in a more peripheral stratum, it must also hold in a more central grammar. Evidence exists from a number of languages that supports this structure: Ito & Mester offer evidence from Japanese, Jamaican Creole and German. Pierrehumbert (2006) shows that a similar situation exists in English in the Latinate/Germanic split in English. Bamgboṣe (1967:273) and Archangeli & Pulleyblank (1989:182-183) showed that ATR vowel harmony happens in Yorùbá native items only, with exceptions among English loans. The current study explores whether Thai fits this pattern. The prediction is that the restrictions seen in Experiment 1, with stimuli interpreted as loan words, should be a subset of those seen in Experiment 2, with stimuli interpreted as native words.

The studies above show that lexical stratum plays a significant role in judgment tasks. The strategy in this experiment is to manipulate other variables that will push interpretation of nonce stimuli towards a loan interpretation or towards a native interpretation in order to test if grammaticality is sensitive to loan versus native stratum

differences. Two variables are manipulated between two experiments in order to do so; these are 1) task instructions, and 2) the language used by the experimenter. Experiment 1 was designed to allow for stimuli to be interpreted as English loans, while Experiment 2 was designed to bias participants to interpret stimuli as native items.

First, regarding task instructions, other studies have successfully incorporated instructions that favor a native interpretation of stimuli. For example, Vance (1980) and Kawahara (2012) presented nonce stimuli as old Japanese words to encourage participants to treat them as native Yamato Japanese items. Since the phonological process under investigation (Lyman's Law) applies to native Yamato words but not to foreign words, it is important that participants treat the nonce words as if they were native items. The results of these experiments implied that the stimuli were treated as native items.

Zuraw (2000:37-38) had a similar motive to Vance & Kawahara in that she wanted Tagalog-speaking participants to treat nonce stimuli as real words in a wug-test production task. She showed pictures of farming implements accompanying each written stimulus, with the expectation that the participants would not be familiar with farming terminology as they did not grow up in rural environments. As such, the stimuli would be interpreted as previously unknown real words for farming implements. The methods employed by these authors are followed in an attempt to encourage participants to interpret stimuli as Thai native words in Experiment 2, where participants are told that one of two stimuli is an ancient Thai word. This task design should encourage interpretation of nonce stimuli as native items, as in Vance (1980), Zuraw (2000), and Kawahara (2012).

Second, regarding the language spoken by the experimenter, there is evidence that this can be an independent factor that influences judgments in tasks like this one. For example, Brunelle & Jannedy (2013) found that in cross-dialectal judgment experiments involving North and South Vietnamese, participants' judgments were affected by the dialect of the experimenter for stimuli that were unfamiliar to them. Hay, Warren & Drager (2010) found that New Zealand English speakers were influenced by the dialect (American vs. New Zealand English) of the experimenter in an "Odd One Out" judgment task. Knowledge of more than one dialect or language affects performance in judgment tasks then. If this effect extends to the loan-versus-native word differences, then it may be possible to influence the participants' treatment of the stimuli as English loans or native Thai words by having an experimenter either speak Thai or English to the participants. Hypothetically, participants in Experiment 2, with the Thai-speaking experimenter would treat the nonce stimuli as native Thai words, while participants in Experiment 1, with the English-speaking experimenter would treat the nonce stimuli as English loan words.²⁸

4.2 Experiment 1

4.2.1 Introduction

Experiment 1 was designed to address whether onset-tone lexical gaps summarized in Chapter 2 are grammatically real. It differs from Experiment 2 in that it allows for interpretation of the stimuli as English loan words since participants are told the stimuli are nonce words by an English-speaking experimenter in the USA. The prediction is that judgments of the onset-tone restrictions will correlate with the lexical gap status of onset-

²⁸ The design here does not allow a distinction to be made between the effect of experimenter language and the effect of the task instructions. The goal was not to make this distinction, but to take advantage of both factors in order to encourage participants in the second experiment to treat stimuli as native Thai items.

tone restrictions in English loan words, as outlined in Chapter 2. The predictions are outlined in detail in Section 4.2.2.5. The following section outlines the experimental method, with the results presented in Section 4.2.3.

4.2.2 *Method*

4.2.2.1 *Stimuli*

This experiment tests the hypothesis that the lexical gaps explored above concerning combinations of onset laryngeal specification (*voiced* – *voiceless unaspirated* – *voiceless aspirated*) and tone within an unchecked syllable are banned in Thai speakers' phonological grammars. Pairs of nonce words are presented aurally and speakers are asked to judge which of the two nonce words sounds more likely to be a Thai word. Nonce words are identified based on whether they satisfy all of the following three criteria: 1) They have a corpus frequency of zero in the ORCHID corpus; 2) they do not occur in Slayden's (2013) online Thai dictionary; 3) they do not occur in Ruangjaroon's (2006) appendices. Any monosyllable that meets all of these three criteria is taken to be a non-word of Thai.

Stimuli pairs are built using only minimal pairs, with the reported *native* lexical gaps in mind. There are two types of minimal pairs. In the first type, the stimuli are identical except for the tone; in the second type, the stimuli are identical except for the onset laryngeal specification. Test stimuli pairs always have one nonce word predicted to be dispreferred if a lexical gap in the *native stratum* is grammaticalized, with the other nonce word predicted to be grammatical. For example, [tó:] and [t^hó:] are one such pair. [tó:] contains an unaspirated onset and a high tone and is thus predicted to be judged less

acceptable than [t^hó:], under a native interpretation of these stimuli. In a separate pair, [tó:] and [tò:] are presented together. For the same reason, [tó:] should be judged less acceptable than [tò:] under a native interpretation of the stimuli. Under an interpretation of the stimuli as English loans, the predictions differ: Since loan strata are more permissive, it is expected that [tó:] will be judged at least as acceptable, and perhaps more acceptable in Experiment 1 than it is in Experiment 2, for example.

In addition to the test stimulus pairs, control comparisons were included to ensure that speakers did not simply have a general preference for low tone over high tone or for aspirated stops over unaspirated stops. These comparisons also test whether markedness constraints affect grammaticality between attested onset-tone sequences. The [tó:]-[t^hó:] comparison is coupled with a control comparison between [tò:] and [t^hò:]²⁹. If the unaspirated onset-high tone ban is grammaticalized, then speakers should choose [t^hó:] in the first comparison more often than they choose [t^hò:] in the second comparison. Likewise, there should be more [tò:] choices in the [tó:]-[tò:] comparison than the number of [t^hò:] choices in a [t^hó:]-[t^hò:] control comparison. Table 24 illustrates this design schematically. Each of four stimulus conditions has its own cell in the table, with arrows showing the different comparisons. The two test comparisons include the bottom left cell (hypothetically ungrammatical), while the two control comparisons do not.

²⁹ Low tone and aspirated onset manner were chosen as control conditions. Low tone has a native lexical distribution that is more similar to high tone (falling and mid tone are attested in the Thai lexicon at a very high frequency), and so lexical frequency effects are minimized by using low tone as a baseline.

Table 24
Stimulus Design for *Unaspirated-high* ban

	H Tone	L Tone
Aspirated Onset	Grammatical	Grammatical
Unaspirated Onset	Ungrammatical	Grammatical

In addition to the *unaspirated onset-high tone* combination, three separate parallel investigations for the *voiced onset-high tone* combination, the *unaspirated onset-rising tone* combination, and the *voiced onset-rising tone* combination were included. Since Thai speakers would need to learn the bans on the basis of lexical gaps, it is possible that they are sensitive to the extent of the gap in giving grammaticality judgments. Additionally, the rising tone gaps are present in both loan and native words, whereas the high tone gaps are present only in native words.

Stimulus pairs were formed using the full variation of onset place of articulation and vowel quality.³⁰ Only CV: monosyllables were used. The Thai lexicon provides us with a total of 192 stimuli pairs where both members in the pair are nonce words. Thirty-two of these pairs were presented twice, with the order of presentation differing; these pairs were chosen based on the fact that the LND was the same for both members of the pair. A total of 224 stimulus pairs were used then. The experiment took 20 minutes per participant.

Stimulus pairs were built using Praat (Boersma & Weenink 2005). First, each token was isolated as a separate .wav file; a Praat script that normalized amplitude was run. Pairs were then joined together with 1 second of silence inserted between each of the

³⁰ The vowels [e] and [ɛ] were not used. This decision was made in a pilot experiment that presented orthographic versions of the stimuli; vowel length is not predictable based on orthography for [e] and [ɛ], and it was crucial there was no mistake that the vowels were long. While the final version of the experiment did not use orthographic versions, the same stimuli set was used.

members of a pair. The order of the two items within each pair was pseudo-randomized to ensure that for a given test comparison, an equal-sized sample for each condition was presented both first and second. Likewise, when LND differences between members of a pair existed, it was ensured that the same number of higher-LND stimuli were presented both first and second over the course of the experiment.

4.2.2.2 Recording of Stimuli

The nonce word stimuli were spoken in list form by a native Thai speaker in the Rutgers Phonology Lab. The speaker listed Central Thai as her native language, although she also spent much of her childhood in southern Thailand, and is likely bidialectal as a result. She grew up in a household where Central Thai was spoken predominantly. She was also fluent in English, having spent the past 8 years living in Pennsylvania. She had no physical or cognitive impairments, nor any illnesses that would have affected her speech at the time of recording. The speaker read the list of stimuli in a sound-attenuated booth. An Audio-Technica AT4040 microphone with pop filter was used. It was connected via an XLR cable to an Applied Research & Technology Tube MB amplifier. A second XLR cable connected the amplifier to an M-Audio Delta 1010 sound card; digitization used ASIO drivers. The sound was digitized on a custom-built PC running Windows XP. Audio files containing the stimuli were created at a sampling rate of 44100 Hz using GoldWave. Each stimulus item was read at least three times, with most members of a pair read in sequence. Tokens that contained speech errors were not used.

A potential issue arose because the pronunciation of high tone varies between speakers of Thai. There has been a recent change in the phonetic pronunciation of high

tone. Speakers who are over 60 years old pronounce high tone as high-level, whereas younger speakers pronounce high tone as mid-rising (Bradley 1911; Abramson 1962; Tumtavitikul 1992; Morén and Zsiga 2006; Teeranon 2007; Thepboriruk 2010). This difference among age-groups was confirmed by Teeranon (2007) in an experiment where participants were asked to identify the tone in synthesized stimuli that differed in whether they were phonetically high-level or mid-rising. Participants older than 60 years old identified the high-level stimuli more often as high tone, while participants under 20 years old identified the mid-rising stimuli as high tone more often. Therefore, the manner in which high tone is produced can potentially affect judgments in the current experiment.

The Thai speaker whose voice was recorded here was thirty years old at the time of recording. She produced both high-tone variants in approximately equal numbers in stimuli with aspirated and voiceless unaspirated onsets. However, she only produced the high-level variant in stimuli with voiced onsets, introducing a potential confound.

To address this issue in Experiment 1, stimuli were added that assessed whether participants had a preference between the level and rising variants of high tone. In cases where participants significantly preferred the rising variant, then the *voiced-high* stimuli would be excluded for that participant. Otherwise, the *voiced-high* stimuli with the level variants were included in the analysis. It was discovered that all participants except one chose between the high-tone variants at random, and so it was concluded that both variants were equally acceptable as examples of high tone. Despite this, in the comparisons between *voiced-high* and *aspirated-high* stimuli, only level variants of the *aspirated-high* tokens were used in order to avoid a confound within pairs. In

comparisons involving high-tone stimuli that did not involve voiced onsets, only the rising variants of high tone were used, since they are more prevalent nowadays.

4.2.2.3 Participants

Fourteen native Thai speakers were recruited in the Philadelphia area to participate in the experiment. All were offered compensation and agreed to sign a consent form. They confirmed that they spoke Central Thai and offered their current age as well as the total time they have lived in the USA. All participants were fluent in English, but to differing degrees. None of the participants had any cognitive or auditory conditions that would affect their performance in the experiment.

4.2.2.4 Procedure

As mentioned above, Experiment 1 is meant to encourage interpretation of the stimuli as English loans. This effect does not come from the task instructions however, but from the fact that the experiment was conducted by an English speaker in the USA. The instructions were intended to be neutral, neither encouraging a native interpretation nor encouraging a loan interpretation. Participants were told that they would hear two non-words of Thai. They were asked to choose *which of the two non-words sounded more like it could be a Thai word*. It is likely that stimuli will be interpreted as English loans without needing to explicitly bias participants via the task instructions. The fact that they are told the stimuli are not Thai words, and that they are interacting in English in the USA is expected to encourage loan interpretations of the stimuli. The task instructions

were translated into Thai by a native-speaking Thai linguist who understood the aims of the experiment, and are shown below in (12).

(12) Experiment 1 Instructions

คุณจะได้ยินคำที่มีลักษณะ / เสียงคล้ายกับคำในภาษาไทย 2 คำ

โปรดเลือกคำที่มีลักษณะ / เสียงคล้ายกับคำในภาษาไทยมากที่สุด

ถ้าคุณเลือกเสียงที่ 1 จากนั้น กด “1”

ถ้าคุณเลือกเสียงที่ 2 จากนั้น กด “9”

คุณสามารถใช้เวลาได้นานเท่าที่คุณต้องการในการตัดสินใจเลือกคำตอบ

โปรดกดปุ่มเพื่อดำเนินการต่อ

English Translation:

“You will hear two sounds that sound similar to a word in Thai.

Choose which one sounds like it is more likely to be a word of Thai.

If you choose the first sound (on the left), then press "1".

If you choose the second sound (on the right), then press "9".

You may take as long as you wish to make your choice.

Press any key to continue.”

The experiment was run using SuperLab, with the order of the pairs randomized for each trial. The participants wore Sennheiser HD 280 Pro headphones connected to a MacBook Pro laptop with the SuperLab program running. They were instructed to press “1” on the MacBook Pro keyboard if they preferred the first word and “9” if they

preferred the second word. (13) below illustrates the visual instructions that the participants saw for a given stimulus pair.

(13) Task Instructions for a Stimulus Pair

กด “1” เพื่อเลือกเสียงที่ 1 กด “9” เพื่อเลือกเสียงที่ 2

English Translation: “Press ‘1’ to choose the 1st word; press ‘9’ to choose the 2nd word”

A short practice session preceded the experiment, in which participants encountered seven comparison pairs, chosen in order to expose them to the full variety of stimuli that they would hear. After the practice session, it was confirmed that they understood the instructions and any questions they had were answered by the author.

4.2.2.5 Predictions

The main hypothesis is that four onset-tone restrictions exist in the grammar, in native Thai items. If grammaticality in loans and native items is structured in the way Ito & Mester claim, we expect some subset of these restrictions to be relaxed in loans. In particular, the high-tone restrictions should be relaxed since a relatively large number of loan words violate them. In some cases, the lexical gap status and the structure predicted by Ito & Mester make different predictions. For example, since rising tone and low tone are essentially unattested in English loan words, it is possible both will be treated as ungrammatical in loans. However, Ito & Mester’s theory predicts these should be grammatical in loans, since they are grammatical in native items.

Table 25 below summarizes the status of the lexical gaps in unchecked syllables,

based on whether each is unattested, under-represented, or attested in a given lexical stratum.

Table 25
Lexical Gap Status in Unchecked Monosyllables

	Onset	Mid Tone	Low Tone	Falling Tone	High Tone	Rising Tone
Native	C _{else}	Attested	Attested	Attested	Attested	Attested
	T	Attested	Attested	Attested	Under-Represented	Under-Represented
	D	Attested	Attested	Attested	Unattested	Under-Represented
English Loans	C _{else}	Attested	Unattested	Under-Represented	Under-Represented	Unattested
	T	Attested	Unattested	Under-Represented	Under-Represented	Unattested
	D	Attested	Unattested	Under-Represented	Under-Represented	Unattested ³¹

The predictions among each comparison category for each experiment are shown in Table 26 below. For the lexical gap hypothesis in Experiment 1, it is assumed that differences both between “attested” and “under-represented” and between “under-represented” and “unattested” sequences will result in grammaticality differences. Since the two high-tone restrictions are under-represented and the corresponding low-tone sequences are unattested in English loan words, it is expected that the *unaspirated-high*, *voiced-high* and *aspirated-high* sequences should actually be preferred in Experiment 1, based on lexical gap status. All other test comparisons involve choices between two under-represented sequences. As a result, we expect participants to select at random, in

³¹ There is a single exception that on its own accounts for slightly more than 1% of voiced-initial unchecked syllables with rising tone; however this is treated as a single exception, rather than as a truly under-represented sequence.

contrast to Experiment 2.

Table 26
Experimental Predictions by Comparison Type³²

	Stimulus 1	Stimulus 2	Experiment 2 – Predicted Preference in Native Words	Experiment 1 – Predicted Preference in English Loans (Lexical Gap)	Experiment 1 – Predicted Preference in English Loans (Ito & Mester (1995))
Test Comparisons	UH	UL	UL	UH	UL or Same
	UH	AH	AH	Same	AH or Same
	VH	VL	VL	VH	VL or Same
	VH	AH	AH	Same	AH or Same
	UR	UL	UL	Same	UL or Same
	UR	AR	AR	Same	AR or Same
	VR	VL	VL	Same	VL or Same
	VR	AR	AR	Same	AR or Same
Control Comparisons	AH	AL	Same	AH	Same
	UL	AL	Same	Same	Same
	AR	AL	Same	Same	Same
	VL	AL	Same	Same	Same

4.2.2.6 Statistical Analysis

The results were analyzed in a logistic regression model, implemented in R 2.15.2 with the *lmer* function, part of the *lme4* package. P-values for fixed effect estimates in the linear mixed model are based on a Wald Z-test. The experiment was designed to test whether combinations of onset laryngeal manner (*voiced* – *voiceless unaspirated* – *voiceless aspirated*) and tone (*high* – *low* – *rising*) affect responses in a forced-choice judgment task. The basic model used was one where participant response varied with the independent factors “tone” and laryngeal onset manner (“manner” from this point

³² Here and throughout, the following short-hand notation for each onset-tone sequence is occasionally used: “AH” is *aspirated-high*, “UH” is *unaspirated-high*, “VH” is *voiced-high*, “AR” is *aspirated-rising*, “UR” is *unaspirated-rising*, and “VR” is *voiced-rising*.

forward) crossed, with “participant” as a random effect (response ~ tone * manner + 1|participant). A significant difference for effects between Experiment 1 and 2, were tested by adding in “Experiment” as an independent factor, pooling the results for both experiments together.

Coding of the dependent response variable required splitting the data into two groups, with logistic regression analysis run separately on each partition. This was the case because each stimulus item was involved in two different comparisons: The first group involved comparisons with tone held constant, and laryngeal onset manner varied (i.e. [tó:] – [tʰó:]); the second group involved comparisons with laryngeal onset manner held constant, and tone varied (i.e. [tó:] – [tò:]). In these two examples, a choice in favor of [tó:] should not be treated as the same since the alternative choices differ in whether they vary the laryngeal manner or the tone. However, by separating the data into two groups corresponding to each type of comparison, a consistent alternative exists within each group, enabling meaningful binary coding of the dependent response variable. For example, in the first group in which manner varies (i.e. [tó:] – [tʰó:]), all choices are made with a control stimulus that is exactly the same, except it has a voiceless aspirated onset. The dependent variable was coded as “0” in cases where the aspirated stimulus was chosen, and as “1” in cases where the unaspirated or voiced stimulus was chosen. In the second group, where tone varied within each stimulus pair, (i.e. [tó:] – [tò:]), the alternative choice will always be low tone. The dependent response variable was coded as “0” when the low tone stimulus was chosen, and as “1” when the high or rising tone stimulus was chosen. Therefore, the “1” choices always involved a choice in favor of a stimulus containing one of the onset-tone restrictions.

Recall that the hypothesis of the experiment is that stimuli with one of the onset-tone sequences involved in a lexical gap will be dispreferred to stimuli without such sequences, if it is in fact ungrammatical. Recall also that four sequences are being tested (*voiced-high, unaspirated-high, voiced-rising, unaspirated-rising*). A logistic regression model assigns coefficients to each factor on its own as well as interaction terms, in this case between tone and manner, forming a linear combination of each term that will account for the response data. Coefficients for each term indicate the log-odds for response “1” based on that term.

This is illustrated with an example for the factor “unaspirated manner” in comparisons involving high and low tone. In this case, the null hypothesis is that there is no difference between a high-low tone decision with aspirated onsets and a high-low tone decision with unaspirated onsets (i.e. they are equally acceptable). This hypothesis is rejected if the coefficient is significantly non-zero under the Wald Z-test. The specific expectation is that a negative coefficient will be seen for unaspirated and voiced manner if the onset-tone sequence is ungrammatical. This is because we expect participants to be biased away from the “1” response (the hypothetically ungrammatical one), resulting in negative log-odds. In cases where a coefficient is insignificant this would mean that we cannot reject the null hypothesis, and the onset-tone sequences in question are equally acceptable. While the previous example used comparisons varying tone, a different prediction is made in comparisons varying manner. In these comparisons, ungrammaticality of a given onset-tone sequence will correspond to negative coefficients for the two “tone” factors.

However, other factors, such as LND, vowel quality and onset place of articulation

may also affect responses, and since only those stimuli pairs that were both non-words in Thai could be used, the stimuli are not evenly distributed with respect to these additional factors. As a result, effects for LND, vowel quality and onset place of articulation were tested as well, to ensure that main effects for tone and/or laryngeal manner weren't merely artifacts of the way the stimuli were built. To ensure this, the basic model (response ~ tone * manner) was compared to similar models with each of LND, vowel quality and onset place nested in a stepwise fashion. If an effect that was significant in the basic model was also significant in the new model, this confirmed that the added factor did not play a role in predicting the main effect, and could be ignored.

4.2.3 Results

4.2.3.1 Onset-Tone Restrictions

Of the four onset-tone combinations tested, only the *voiced-rising* sequence was dispreferred, consistent with the Ito & Mester hypothesis, where loan strata are more permissive. In addition participants disfavored the *unaspirated-high* sequence. However this was only significant in comparisons varying tone, but not in comparisons varying manner. Finally, *voiced-high* sequences were unexpectedly favored in choices varying tone, but participants responded at random in choices where manner varied. The results across participants are shown in Figure 14 below, with 95% confidence intervals included. In the eight test comparisons, if the consonant-tone sequences are ungrammatical, participants should choose the “0” responses, (bottom of the chart). A response mean closer to “1” (top of the chart) indicates a preference for the hypothetically ungrammatical onset-tone sequence.

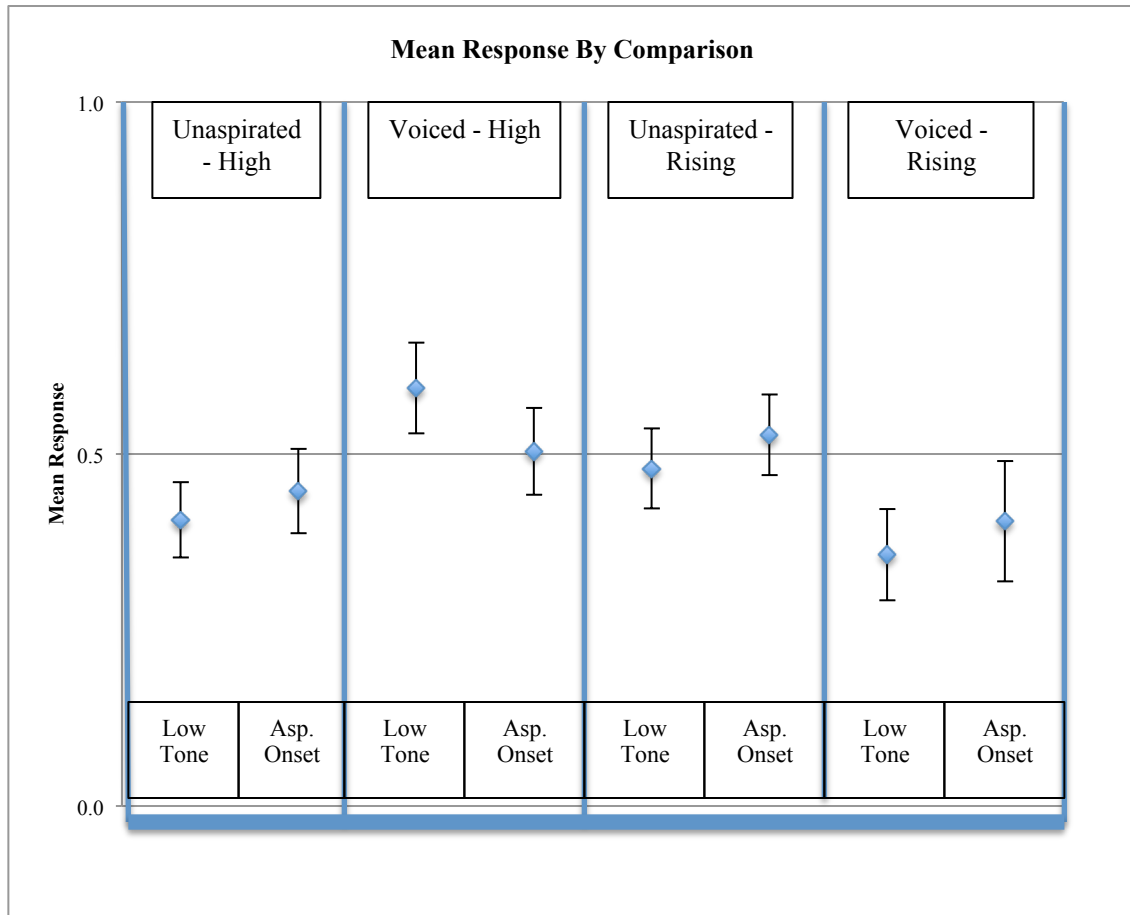


Fig. 14. Experiment 1 Results – Test Comparisons

Logistic Regression results for the basic model with tone and manner crossed are summarized for both comparison types in Table 27 below. Recall that ungrammaticality is confirmed via significant negative coefficients for ‘tone’ in comparisons varying manner and via significant negative coefficients for ‘manner’ in comparisons varying tone.

Table 27

Logistic Regression Results – Experiment 1

* - indicates significance with $p < 0.05$

Manner Varying – Voiced/Unaspirated (1) – Aspirated (0)	Estimate	Std. Error	z-value	p-value
Intercept (Unaspirated vs. Aspirated, L tone)	0.028	0.135	0.206	0.837
Tone (H)	-0.242	0.171	-1.421	0.155
Tone (R)	0.083	0.166	0.501	0.617
* Manner (Voiced vs. Aspirated)	0.403	0.192	2.096	0.036
Tone (H): Manner (Voiced vs. Aspirated)	-0.172	0.261	-0.658	0.511
* Tone (R): Manner (Voiced vs. Aspirated)	-0.905	0.290	-3.124	0.002

Tone Varying – H/R tone (1) – Ltone (0)	Estimate	Std. Error	z-value	p-value
Intercept (Aspirated, H vs. L tone)	0.052	0.123	0.427	0.670
Tone (R vs. L)	-0.124	0.176	-0.706	0.480
* Manner (Unaspirated)	-0.432	0.161	-2.682	0.007
Manner (Voiced)	0.330	0.178	1.855	0.064
Tone (R vs. L): Manner (Unaspirated)	0.422	0.240	1.758	0.079
* Tone (R vs. L): Manner (Voiced)	-0.850	0.265	-3.204	0.001

Neither high tone nor rising tone was significant in comparisons varying manner, and voiced manner was not significant in comparisons varying tone. Only unaspirated manner had a significant negative coefficient in comparisons varying tone. This indicates that a preference for low tone over high and rising tone is seen with unaspirated onsets, but that no other general preferences exist. However, the presence of significant interaction terms indicate that there is more to the story here, specifically that the *voiced-rising* sequence was judged as worse than the others. In comparisons with manner varying, a significant negative interaction between rising tone and the voiced-aspirated condition was discovered. This indicates a significant difference between responses for *voiced-rising* and *unaspirated-rising* sequences. In comparisons with tone varying, where the choice was between rising and low tone, a significant difference between responses for *voiced-rising* and *voiced-high* sequences was seen. Together, these results suggest that the *voiced-rising* combination is less acceptable than the *voiced-high* and the *unaspirated-*

rising sequences. In addition, this result is consistent with a preference for *voiced-high* sequences over *voiced-low* sequences, which is very apparent in Figure 14.

While the *voiced-rising* and *voiced-high* sequences were the most significant results here, they were not the only ones to reach significance. In comparisons varying tone, a significant effect for *unaspirated* manner was discovered, with a negative coefficient. This indicates that there is a preference for low tone over both rising and high tone, when the onset is unaspirated. Note that the *unaspirated-rising* sequence did not appear to be significantly dispreferred in Table 27, however. Confirmation of this is seen in the coefficient for the interaction between tone and unaspirated manner, which was very nearly significant ($p = 0.079$). The positive sign of the coefficient for this interaction term accounts for the fact that the *unaspirated-rising* sequence is not actually dispreferred significantly. The negative effect for unaspirated onsets in general is nearly cancelled out by the positive interaction term. However, while this difference between the *unaspirated-high* sequence and the *unaspirated-rising* sequence did not quite reach significance, the effect of manner here is in the expected direction if the unaspirated restrictions are real: Unaspirated onsets are dispreferred with high (and rising) tone.

These results, taken together, suggest that the *unaspirated-rising* combination and the *voiced-high* combination are grammatical in the loan stratum of Thai. The *unaspirated-high* sequence, on the other hand, is found to be dispreferred only in comparisons varying tone, but not in comparisons varying manner. The preference for *voiced-high* sequences is consistent with a loan interpretation of these stimuli, based on lexical gap status in Thai, where *voiced-high* sequences are under-represented, but *voiced-low* sequences are completely unattested. However, the results for the *unaspirated-high* sequences are

inconsistent with the lexical gap status in English loans. *Unaspirated-low* sequences are preferred over *unaspirated-high* sequences, even though the former are unattested in English loans, while the latter are merely under-represented.³³ The low-tone gap in loan words must be an accidental gap then, and not one represented grammatically. This result is consistent with the Ito & Mester hypothesis: Since low tone is grammatical in native items (with any tone), we do not expect it to be ungrammatical in the English loan stratum.

4.2.3.2 Preferences Between Grammatical Stimuli

Turning now to the results in the control comparisons, it is expected that responses should be at random, since both stimuli have attested onset-tone combinations. However, this was not the case for all of the four control comparisons. Participants preferred the *voiced-low* sequence to the *aspirated-low* sequence. 95% confidence intervals for the mean responses of the four control comparisons are plotted below in Figure 15.

³³ While, the *unaspirated-high* and *voiced-high* combinations were actually under-attested in English loans, recall that high tone is actually the second most prevalent tone among English loans, regardless of the onset. This fact may suggest it is grammatical in the loan stratum.

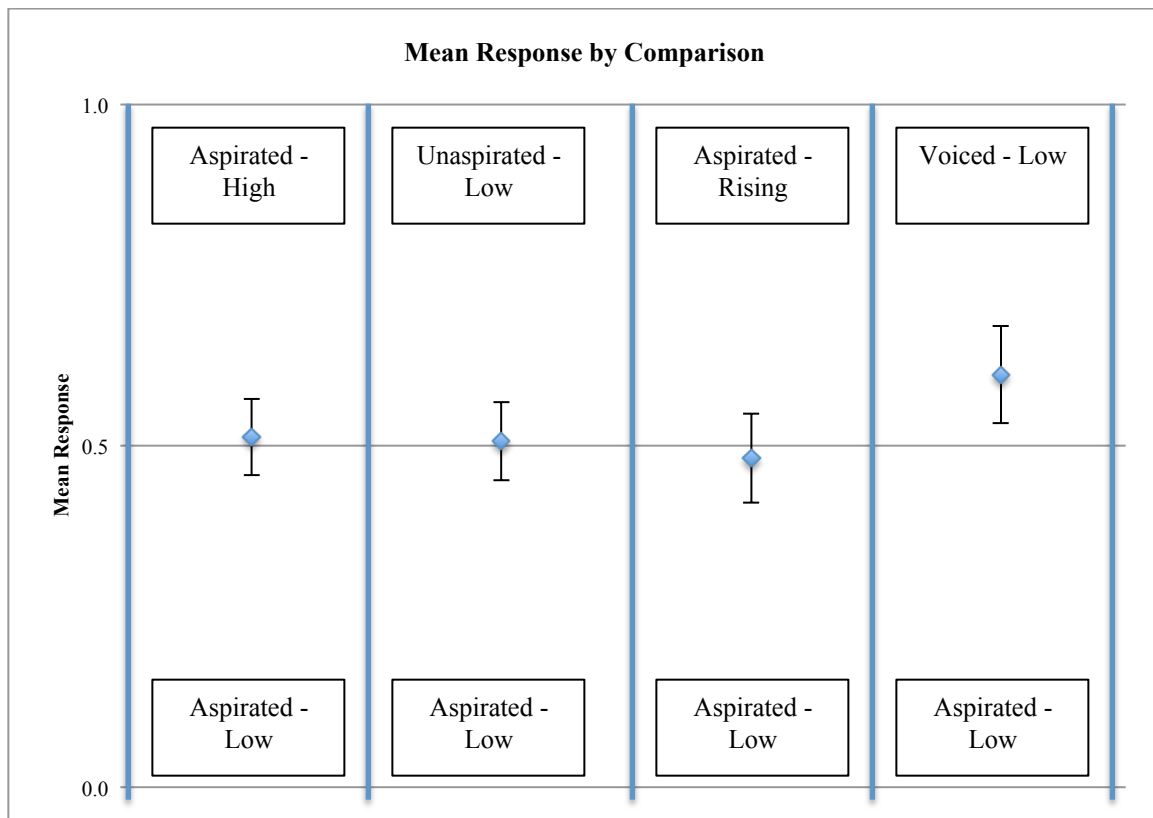


Fig. 15. Response Means – Control Comparisons

As the rightmost graph shows, responses were significantly biased towards the *voiced-low* sequence compared to the *aspirated-low* sequence. This result is seen in the logistic regression analysis where a significant positive coefficient for manner is seen in comparisons varying manner. This positive coefficient means that participants preferred voiced onsets more than they did aspirated onsets in comparisons with low tone. This is unexpected since both *voiced-low* and *aspirated-low* combinations are equally attested in Thai.

This preference is, however, in accordance with theories of markedness of consonant-tone interaction, where voiced stops and low tone have an affinity for one another (Bradshaw 1998; Lee 2008; Tang 2008). This result is in agreement with the findings of

Coetzee (2008) & Frisch & Zawaydeh (2001), where it is argued that speakers exhibit preferences that cannot have been learned from language experience. Therefore, these findings constitute evidence that people have knowledge of markedness constraints that are not directly involved in learning the grammar of their language.

4.2.3.3 *Additional Factors (LND, Vowel Quality, Onset Place)*

To ensure that other factors didn't play a significant role, logistic regression models that individually nested LND, vowel quality, and onset place of articulation were compared with the basic model that attributed responses to an interaction between tone and manner.³⁴ LND did not have a significant effect on responses in either comparison type (Comparisons varying manner: $Z = -0.151$, $p = \text{n.s.}$; Comparisons varying tone: $Z = -1.382$, $p = \text{n.s.}$). However, a closer inspection of LND revealed a noticeable effect when considering only stimuli pairs with large differences in LND. Participants were more likely to choose nonce words with higher LND when the difference was large. This effect is marginal, and since most stimuli pairs contained only small LND differences, this explains why the effect was not significant in the logistic regression over the entire data set. Figure 16 below illustrates responses across all comparisons categorized by whether the higher-LND nonce word or the lower-LND nonce word was selected.

³⁴ While this is a larger concern in Experiment 2, where stimuli are treated as native lexical items, it is still possible that judgments may be affected by lexical frequency effects, even under a loan interpretation.

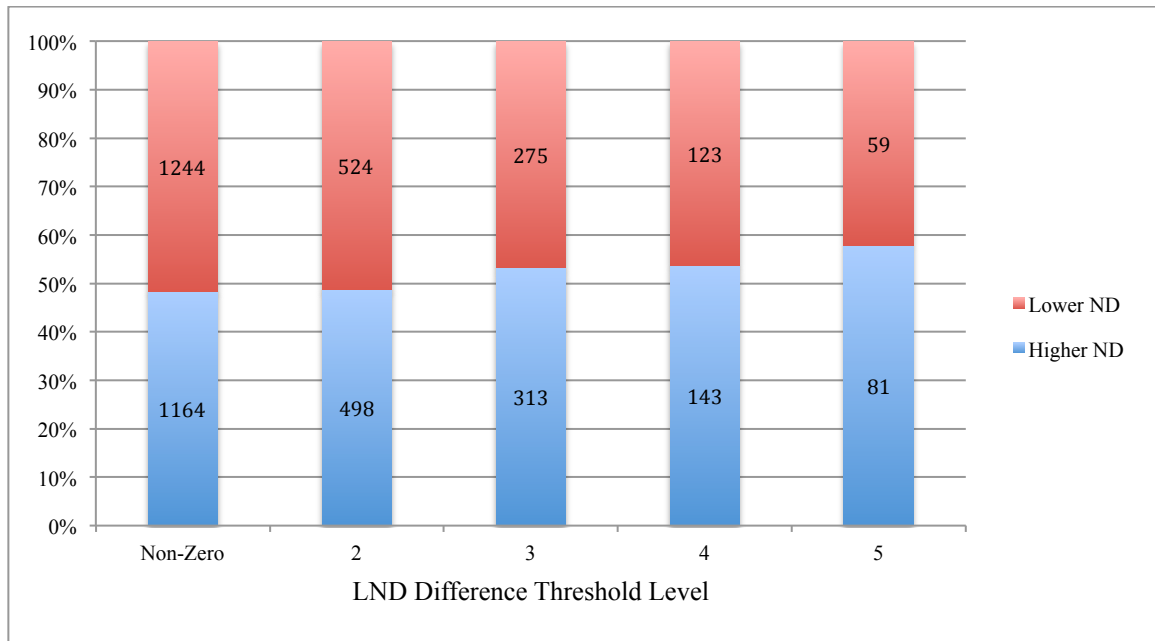


Fig. 16. Responses categorized by LND Difference

Each bar graph depicts responses for a subset of the data, consisting only of comparisons whose stimuli had LND's greater than the threshold. For example the second bar includes only stimuli pairs with an LND difference greater than 2. In this case, 524 choices were made in favor of the higher-LND stimulus and 498 choices in favor of the lower-LND stimulus. As the minimum threshold is increased incrementally, decreasing the size of the data-set, so that only stimuli pairs with larger LND differences were included (left-to-right in Figure 16), more choices in favor of the higher-LND stimulus item are chosen. However this effect is quite small (~58%), even at LND differences greater than 5. This may indicate that the measure of LND used here is a crude approximation of the actual way that knowledge of lexical neighborhood density works. However, the fact that the LND effect is small may be unsurprising considering the experiment was designed using nonce stimuli, which are known to minimize lexical effects on judgments. Additionally, studies that use monosyllabic stimuli have been

found to minimize lexical effects (Coetzee 2008; Cutler et al. 1987).

While the effects of LND are small, significant effects for vowel quality were discovered in both comparison types. In comparisons where tone was varied, an effect was discovered only for the vowel [i], as compared to the vowel [u] as a baseline ($\beta = 0.596$, $Z = 2.027$, $p < 0.05$). In comparisons varying high and low tone, 31 choices were made for high tone (74%) and only 11 choices for low tone (26%), indicating a preference for [i] in stimuli with high tone.³⁵ However, the main effects indicated in Table 27 above, for unaspirated manner and the interaction between rising tone and voiced manner remained significant, indicating that the effects of vowel quality did not confound the main onset-tone effects.

Meanwhile, in comparisons varying manner, the vowels [i] ($\beta = 1.801$, $Z = 2.675$, $p < 0.01$), [ia] ($\beta = 1.230$, $Z = 2.078$, $p < 0.05$), and [u] ($\beta = 1.517$, $Z = 2.272$, $p < 0.05$) had significant effects on responses; the positive sign on the coefficient indicated that more unaspirated and voiced choices were made for these vowels. Importantly, when vowel quality was added to the model, the effect of manner was not significant ($\beta = 0.196$, $Z = 0.204$, $p = \text{n.s.}$). However, the effect of the interaction of rising tone with voiced manner was still significant, indicating that vowel quality wasn't confounding the main effects of onset-tone interaction described above. Finally, effects of place of articulation were not significant in either comparison type.

³⁵ There is some cross-linguistic evidence of phonological and phonetic relationships between vowel height and tone; there is an affinity for high tone to couple with high vowels and for low tone to couple with low vowels (Wright 1983; Maddieson 1997; Yip 2002: 32-33). In comparisons where the Thai participants chose between high tone and low tone, they chose high tone more often for the high vowels [i] and [u], and low tone more often for the low vowel [a]. Thus, the correlation between vowel quality and tone here indicates that this may be encoded in the grammar.

4.2.3.4 Conclusion

In conclusion, the results showed that of the four onset-tone sequences constituting gaps in the native Thai lexicon, only the *voiced-rising* sequence is ungrammatical in the English loan stratum. Second, there is evidence that the *unaspirated-high* sequence is dispreferred, but only in comparisons varying tone; the logistic regression results suggested that this dispreference did not quite reach significance in comparisons varying manner. Third, *voiced-high* sequences are actually preferred to *voiced-low* sequences, a fact that may have an explanation in phonotactic frequency effects in English loans: *Voiced-high* sequence loan words are attested, while *voiced-low* words are not. The result that only one of the four hypothesized onset-tone restrictions exists in the English loan stratum is consistent with Ito & Mester's theory that restrictions in loan strata constitute a subset of those in native strata. Finally, an unexpected preference was seen for *voiced-low* sequences over *aspirated-low* sequences. This preference implies the activity of a markedness constraint that encodes an affinity for voiced stops with low tone. The Experiment 1 results are summarized in Table 28 below.

Table 28
Experiment 1 - Summary of Results & Predictions

	Stimulus 1	Stimulus 2	Experiment 1 – Predicted Preference in English Loans (Lexical Gap)		Experiment 1 – Predicted Preference in English Loans (Ito & Mester's Theory)		Experiment 1 Results
Test Comparisons	UH	UL	UH	✗	UL or Same	✓	UL
	UH	AH	Same	✓	AH or Same	✓	AH (n.s.)
	VH	VL	VH	✓	VL or Same	✗	VH
	VH	AH	Same	✓	AH or Same	✓	Same
	UR	UL	Same	✓	UL or Same	✓	Same
	UR	AR	Same	✓	AR or Same	✓	Same
	VR	VL	Same	✗	VL or Same	✓	VL
	VR	AR	Same	✗	AR or Same	✓	AR
Control Comparisons	AH	AL	AH	✗	Same	✓	Same
	UL	AL	Same	✓	Same	✓	Same
	AR	AL	Same	✓	Same	✓	Same
	VL	AL	Same	✗	Same	✗	VL

4.2.4 Discussion

4.2.4.1 The Voiced-high Preference

Responses for the *voiced – high* combination went in different directions depending on whether the stimuli pairs varied in their tone or in their onset laryngeal manner, as described above. The results are repeated in Figure 17.

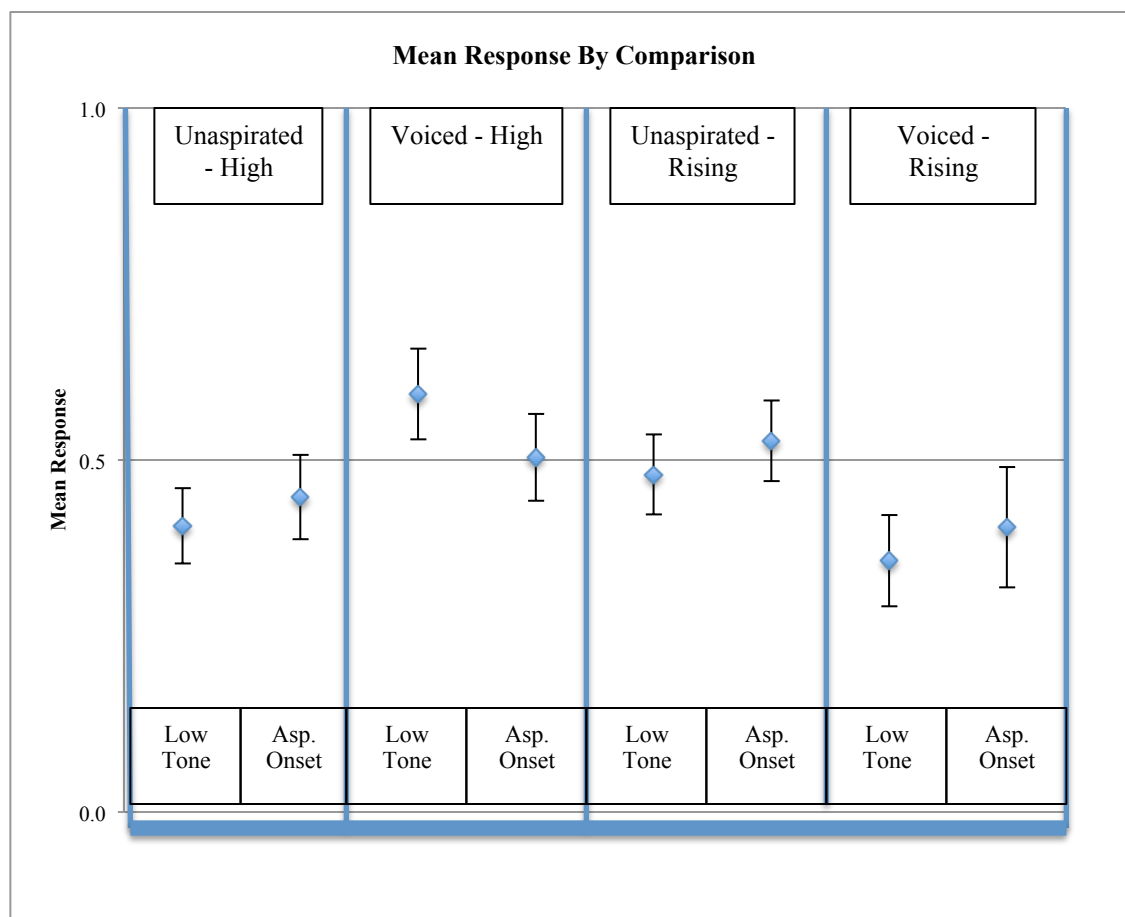


Fig. 17. Experiment 1 Results – Test Comparisons

In comparisons with manner varying, participants responded at random. However, in comparisons with voiced onsets that varied tone, there were more responses in favor of the *voiced-high* combination. This result is exactly the one predicted based on the lexical gap status in English loans, and is the only result among the test comparisons that is not explained by Ito & Mester's theory of structured lexical stratification. While the *voiced-high* restriction may be relaxed in the loan stratum, it is surprising that participants would be biased in the opposite direction. If this preference is due to the grammar, this would imply a markedness flip in the loan stratum, contrary to Ito & Mester 1995, 1999, 2001).

Therefore this section explores an alternative possibility, that the *voiced-high* preference is due to a frequency effect in English loan words.

If this is correct and knowledge of onset-tone sequence frequency in the loan stratum can influence acceptability judgments, it is not clear why such a frequency bias should exist only for *voiced-high* sequences, and not for other high-frequency sequences. For example, the *unaspirated-high* sequence is actually more frequent than the *voiced-high* sequence in English loan words. However, participants prefer the unattested *unaspirated-low* sequence to the *unaspirated-high* sequence, consistent with a grammatical ban, but not with lexical frequency. Likewise, lexical frequency did not affect judgments involving *voiced-rising* sequences. *Voiced-rising* sequences are unattested in English loans, just like the *aspirated-rising* and *voiced-low* sequences with which they are compared. However, the *voiced-rising* sequence is dispreferred, consistent with a grammatical restriction, but not with a frequency effect in loan words. These facts suggest that lexical frequency of loans is affecting judgments in the *voiced-high* sequence to a greater extent than other onset-tone sequences.

A possible explanation is that participants are not treating all stimuli pairs in Experiment 1 equally as English loans. Perhaps they are sensitive to differences in phonotactic probability between loan and native strata (a result confirmed by Moreton & Amano (1999) for Japanese speakers). When counting the number of words in English loans and native Thai words categorized by onset-tone sequence (across all syllable types), the *voiced-high* combination is the only one where there are significantly more English loan words than native Thai words. This is summarized graphically in Figure 18 below for each onset-tone combination used in the stimuli.

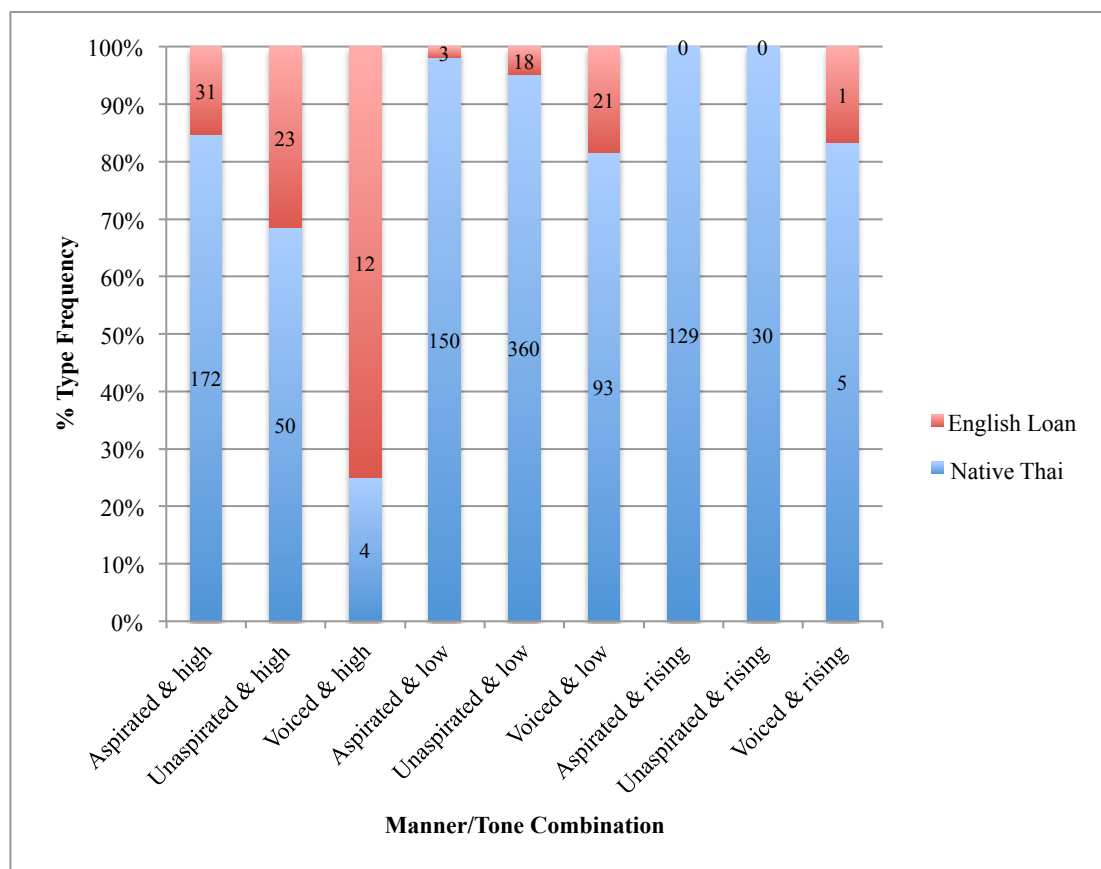


Fig. 18. Loan Distribution in the Thai Lexicon classified by Onset-Tone Combination

If participants are primed for either a loan or native interpretation based on the onset-tone combination³⁶, then of all the onset-tone combinations, they will be most likely to treat words with *voiced-high* sequences as English loan words. This would explain the fact that the *voiced-high* sequence was preferred over the *voiced-low* sequence: *Voiced-high* sequences are more natural in loan words than *voiced-low* sequences, as evidenced by the larger percentage of loan words in Figure 18. However, the same logic would also predict that *voiced-high* sequences would be preferred to *aspirated-high* sequences. This

³⁶ It seems likely that if anything would, onset-tone combinations would prime loan or native interpretations of the stimuli, given this is the main dimension of variation among the stimuli.

is not the case though.

One possible explanation for the *voiced-high* preference is that there are enough examples of it occurring in loan words and few enough examples in native words for Thai speakers to single that sequence out as one that is typically English loan-like and not native-like. In the case of other onset-tone sequences in Figure 18 above, there are more occurrences in the native lexicon and fewer occurrences in loan words. Rising tone does not occur at all in loan words and is of course plentiful in native items, and so no other possible phonotactic pattern meets this criterion of positive evidence in the loan stratum and negative evidence in the native stratum. Again, it is not clear why the *voiced-high* sequence isn't also preferred to the *aspirated-high* sequence. This particular asymmetry remains unexplained.

Importantly, this solution does not say anything about the Thai grammar, in loans or native items. It is a specific version of a theory of lexical frequency affecting acceptability judgments. In the absence of other grammatical and lexical effects, participants may prefer phonotactic sequences that are present in the stratum they are working in if they are more prevalent in that stratum than another competing stratum, in accordance with Moreton & Amano (1999).

4.2.4.2 *Voiced-Low Affinity: Preference for an Unmarked Onset-Tone Sequence*

Perhaps the most interesting result was that *voiced-low* sequences were preferred over *aspirated-low* sequences. As described above, this preference can be explained by a grammatical constraint that encodes an affinity for voiced stops with low tone. However, this same constraint should also result in a preference for *voiced-rising* sequences,

assuming rising tone is a sequence of L and H tone autosegments. *Voiced-rising* sequences are treated as ungrammatical though. Therefore, this offers evidence of a ranked pair of markedness constraints involving sequences of low tone and [+voice]. It must be the case that a high-ranked markedness constraint banning [+voice]-LH-sequences exists. In addition, a lower-ranked constraint “[+voice]→L Tone” is present. The two markedness constraints conflict, and since *voiced-rising* sequences are judged as ungrammatical, it must be the case that *[+voice]-LH outranks [+voice]→L. [+voice]→L only exerts its influence in the AL-VL comparison. This result is particularly interesting in the context of markedness theory: There is no reason for this markedness constraint to have been learned in the process of acquiring Thai since it is not involved in the Thai grammar. It supports the idea that phonological constraints are innate then. An OT-based phonological account of this is offered in Chapter 5.

4.3 Experiment 2

Ito & Mester (1995, 1999, 2001) predict that loan strata should be more permissive than native strata. Experiment 2 assesses whether onset-tone sequences are restricted to a greater degree in the native Thai lexical stratum than they are in the English loan stratum.

4.3.1 Method

4.3.1.1 Stimuli

The same basic set of stimuli from Experiment 1 was used in Experiment 2. Unlike Experiment 1, a pilot study done for Experiment 2 indicated that participants had strong

preferences between the high-tone variants described in Section 4.2.2.2.³⁷ The rising variant was strongly preferred over the level variant for five of seven participants. In order to address this, stimuli were synthesized that contained voiced onsets with the rising variant of the high tone. The onsets of the synthesized stimuli were taken from tokens that contained the same vowel as the one to be concatenated. Likewise, the vocalic portion of the synthesized stimuli was taken from tokens with onsets at the same place of articulation. Tokens with aspirated onsets were not used since these often were accompanied by breathiness on the vowel, which may act as a perceptual cue for aspiration. The sound files were concatenated using Praat at zero-point crossings. To avoid a potential confound within stimulus pairs, the alternative to the *voiced-high* sequence (either *voiced-low* or *aspirated-high*) was also spliced in the same manner. Nine spliced stimuli pairs comparing *voiced-high* and *voiced-low* sequences and ten spliced pairs comparing *voiced-high* and *aspirated-high* sequences were added to the stimuli list for Experiment 2 then. The level high-tone variant stimuli were retained in both experiments, but were not included in the statistical analysis in Experiment 2, replaced instead by the rising high-tone variants. The fact that participants in Experiment 1 did not judge the rising and level high-tone variants as different was taken as justification that this did not introduce a between-experiment confound for the *voiced-high* sequence.

³⁷ It is interesting that this preference was seen in Experiment 2 but not Experiment 1. One possibility is that the task instructions may have affected interpretations of the high tone. It is possible that participants were more permissive with “deviant” tone pronunciations when they thought stimuli were non-words, as in Experiment 1. In Experiment 2, they would be less permissive since now they are told one stimulus is an ancient Thai word. This was not an age effect either, as both young and old participants answered at random in Experiment 1.

4.3.1.2 Participants

Sixteen participants were recruited in the Bangkok region of Thailand by a native Thai speaker who was trained in theoretical Linguistics. All were offered compensation and agreed to sign a consent form. They confirmed that they spoke Central Thai and offered their current age as well as information about where they have lived in the past. Eleven of the participants spoke English to varying degrees. Five participants did not speak English at all. None of the participants had any cognitive or auditory conditions that would affect their performance in the experiment.

4.3.1.3 Procedure

Unlike Experiment 1, a native Thai speaker, who was told to only speak Thai with the participants, conducted the experiment. The instructions informed the participants that one of the two nonce stimuli was an ancient Thai word. Their task was to use their knowledge of the sounds of current Thai to choose which of the two stimuli they thought was the ancient Thai word. This task should encourage a native Thai interpretation of the stimuli, and it should discourage an interpretation of the stimuli as English loan words. The instructions, as shown to the participants are given below in (14).

(14) Experiment 2 Instructions

คุณจะได้ยินเสียง 2 เสียง

หนึ่งเสียงเป็นคำในภาษาไทยเดิม และอีกหนึ่งเสียงไม่ใช่

เลือกเสียงที่คุณคิดว่าน่าจะเป็นคำไทยเดิม โดยพิจารณาจากความรู้เสียงภาษาไทยในปัจจุบัน

โปรดเลือกโดยคิดว่าเสียงในภาษาไทยปัจจุบันเป็นอย่างไร

ไม่ใช่เลือกด้วยความรู้สึกว่าเสียงในภาษาไทยเดิมน่าจะเป็นอย่างไร

หากคุณคิดว่าเสียงแรกที่ได้ยินเป็นเสียงภาษาไทย กด 1 บนแป้นคีย์บอร์ด

หากคุณคิดว่าเสียงที่สองที่ได้ยินเป็นเสียงภาษาไทย กด 2 บนแป้นคีย์บอร์ด

English Translation:

“You will hear two sounds. One of these sounds is a word in ancient Thai while the other is not.

Given what you know about sounds in the modern Thai language, choose which word you think is most likely to be the ancient Thai word. Please base your choice on the way modern Thai sounds in your opinion; do not base your choice on any feelings you may have about the way ancient Thai should sound. If you prefer the first word, press ‘1’ on the keyboard. If you prefer the second word, press ‘9’ on the keyboard.”

Following the experiment, participants were asked to identify the tone in fourteen of the stimuli. This was done primarily as a check on whether the spliced stimuli were perceived correctly, but also provided a way to check for systematic misperceptions (between high and rising tones for example, which are somewhat similar). Participants listened to one stimulus for each condition ($3 \text{ tones} \times 3 \text{ onset manners} = 9 \text{ stimuli}$) with five extra stimuli to check for differences in spliced/unspliced status and high tone level/rising variance.

4.3.2 Results

4.3.2.1 Onset-Tone Restrictions

The results of Experiment 2, summarized in Figure 19 below, confirm that all four

onset-tone restrictions are grammaticalized in the native Thai lexical stratum. The *unaspirated-high*, *voiced-high* and *unaspirated-rising* sequences were all dispreferred in both comparisons varying tone and manner. The *voiced-rising* sequence was slightly dispreferred in comparisons varying tone, but not in comparisons varying manner.

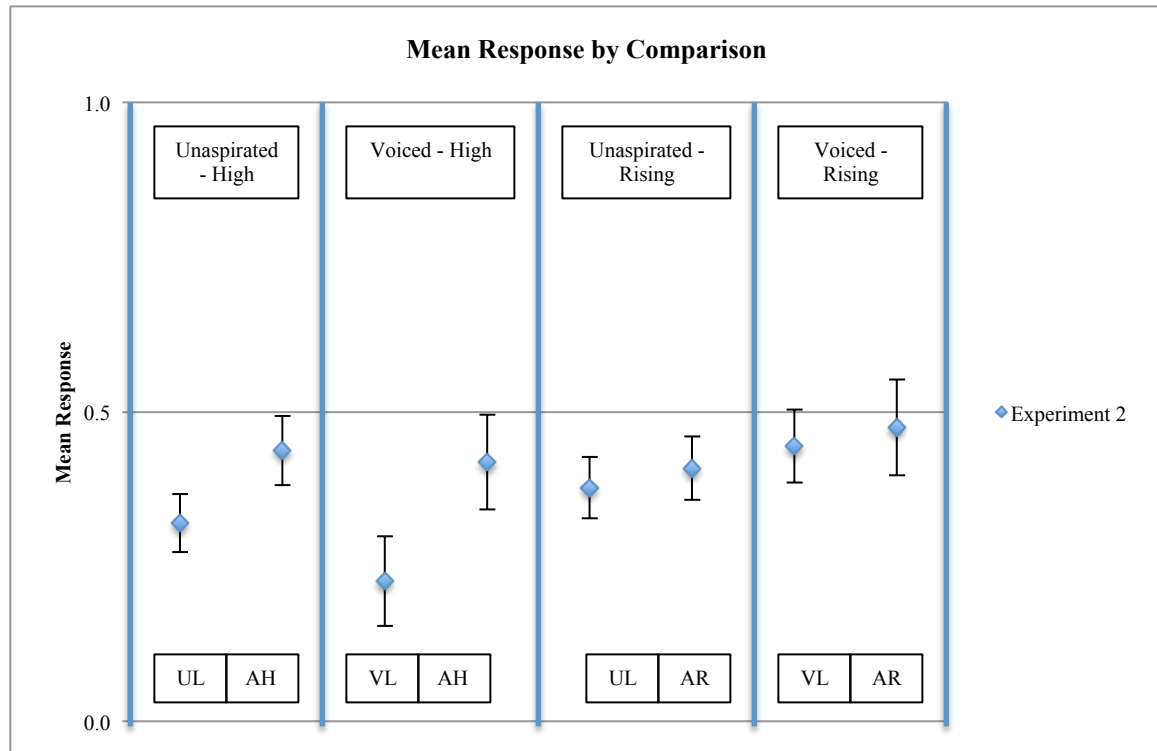


Fig. 19. Experiment 2 Results – Test Comparisons

Linear regression analysis was performed on the Experiment 2 results, and summarized in Table 29 below. Recall that in comparisons varying manner, grammatical status is confirmed for a given tone if the coefficient for that tone is significant and is negative. Likewise, in comparisons varying tone, grammatical status of a given onset-tone sequence is confirmed by a significantly negative coefficient in the two manner factors. The interpretation of the logistic regression coefficients are discussed below.

Table 29

Logistic Regression Results – Experiment 2

* - indicates significance with $p < 0.05$

Manner Varying – Voiced/Unaspirated (1) – Aspirated (0)	Estimate	Std. Error	z-value	p-value
* Intercept (Unaspirated vs. Aspirated, L tone)	0.422	0.140	3.014	0.003
* Tone (H)	−0.679	0.159	−4.272	0.000
* Tone (R)	−0.799	0.154	−5.198	0.000
Manner (Voiced vs. Aspirated)	0.085	0.180	0.472	0.637
Tone (H): Manner (Voiced vs. Aspirated)	−0.164	0.269	−0.610	0.542
Tone (R): Manner (Voiced vs. Aspirated)	0.191	0.265	0.721	0.471

Tone Varying – H/R tone (1) – L tone (0)	Estimate	Std. Error	z-value	p-value
Intercept (Aspirated, H vs. L tone)	−0.086	0.170	−0.505	0.614
Tone (R vs. L)	0.276	0.166	1.660	0.097
* Manner (Unaspirated)	−0.719	0.156	−4.605	0.000
* Manner (Voiced)	−1.212	0.241	−5.037	0.000
Tone (R vs. L): Manner (Unaspirated)	−0.011	0.228	−0.048	0.961
* Tone (R vs. L): Manner (Voiced)	0.774	0.298	2.594	0.010

In comparisons varying manner, a significant negative effect was discovered for both high and rising tones: Participants preferred aspirated onsets more often with high and rising tone than they did with low tone. In comparisons varying tone, significant negative effects for both unaspirated and voiced manner were discovered: Participants preferred low tone more often following unaspirated or voiced onsets than they did following aspirated onsets. This confirms that all four onset-tone restrictions are grammaticalized in the Thai native stratum.

Unlike Experiment 1, no significant interactions were seen in the comparisons varying manner, indicating that high and rising tone comparisons were treated on par: Aspirated stops were preferred slightly and to an equal degree for high and rising tone comparisons. However a significant interaction was observed between tone and voiced manner in comparisons varying tone. This latter result indicates that the dispreference for *voiced-high* sequences is significantly greater than the dispreference for the *voiced-rising*

sequence. This result is clearly observed in Figure 19 above: The preference for *voiced-low* sequences over *voiced-high* sequences is by far the largest bias seen in the experiment (approximately 80%). Both of these results are consistent with the hypothesis that the four onset-tone sequences under investigation are dispreferred.

One additional near-significant result is seen in the coefficient for tone in comparisons varying tone ($p = 0.097$). Notably, the response means in the two high tone comparisons (UH-UL & VH-VL) are much closer to zero than those in the two rising tone comparisons. This indicates that a preference for low tone over high tone is stronger than the preference for low tone over rising tone, but that this difference does not quite reach significance.

4.3.2.2 Preferences Between Grammatical Stimuli Again

Turning to the control comparisons, the result where *voiced-low* sequences were preferred in Experiment 1 is also seen in Experiment 2. However, in addition, there is a significant preference for *unaspirated-low* sequences this time. Recall from Chapter 3 that voiced and unaspirated stops share the feature [+constricted glottis]. This then amounts to evidence that Thai speakers have a general preference for low tone with [+constricted glottis] onsets in the native stratum. Meanwhile, in the loan stratum, this preference does not generalize to [+constricted glottis], but is more specific, applying to [+voice] only. Results for the control comparisons are summarized in Figure 20 below for both experiments.

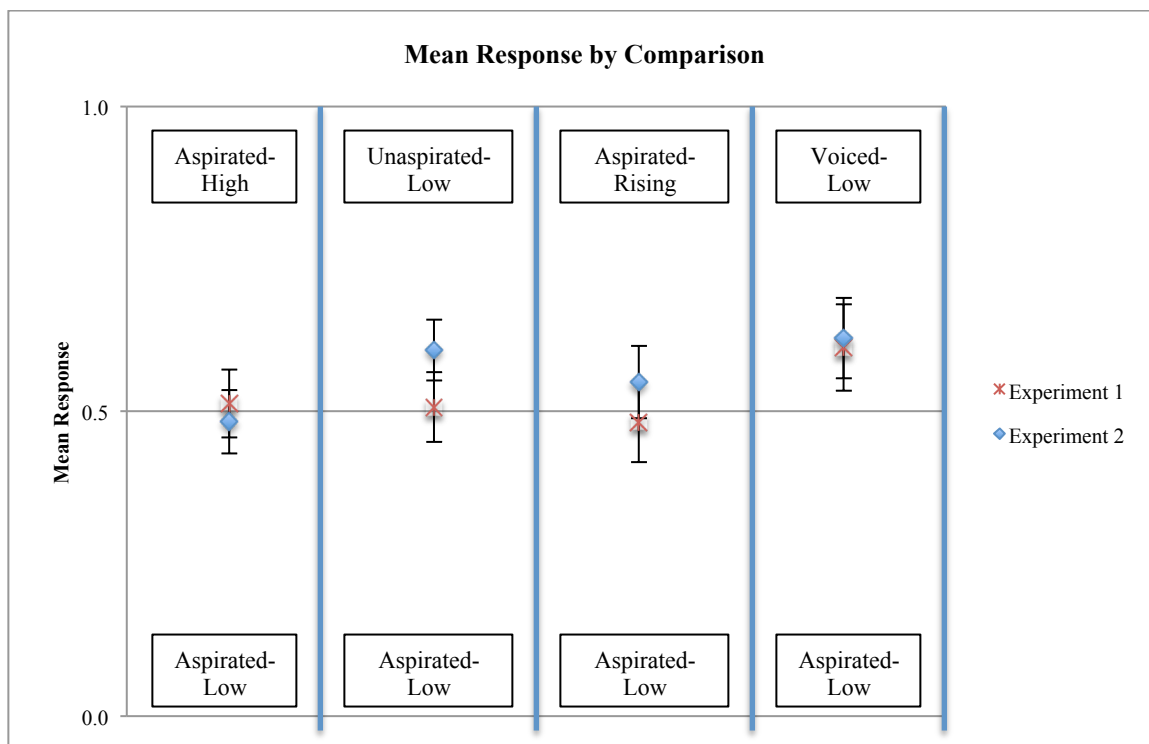


Fig. 20. Experiment 1 & 2 Results – Control Comparisons

The significance of the [+constricted glottis]-low tone preference is confirmed in the linear regression model for comparisons varying manner: The significant positive intercept coefficient in Table 29 indicates that participants are significantly more likely to prefer unaspirated onsets to aspirated onsets with low tone (the base condition). Additionally, the fact that manner is not significant in the regression model indicates that there is no difference in the effects for voiced and unaspirated onsets: Both voiced and unaspirated onsets are preferred with low tone in comparison to the *aspirated-low* alternative.

4.3.2.3 Additional Factors (*LND, Vowel Quality, Onset Place*)

In Experiment 2, it is more likely that an effect of LND will exist since participants were told the stimuli were ancient Thai words. In Experiment 1, on the other hand, they

were told that they were hearing non-words. This effect was noticeable, but very small.

The coefficient in the logistic regression, with LND added to the model, was insignificant among comparisons varying tone ($\beta = 0.001$, $z = 0.042$, $p = 0.966$) and in comparisons varying manner also ($\beta = 0.009$, $z = 0.348$, $p = 0.728$), indicating that LND had no overall effect on responses. (Figure 21 summarizes mean responses across all participants, categorized by whether the item with higher LND or lower LND was chosen. For each pair of bar graphs, the left bar graph shows the results for Experiment 1; the right bar graph shows the results for Experiment 2. Each pair of means is taken from a subset of the data that includes only comparisons that meet the minimum threshold LND difference shown on the x-axis.

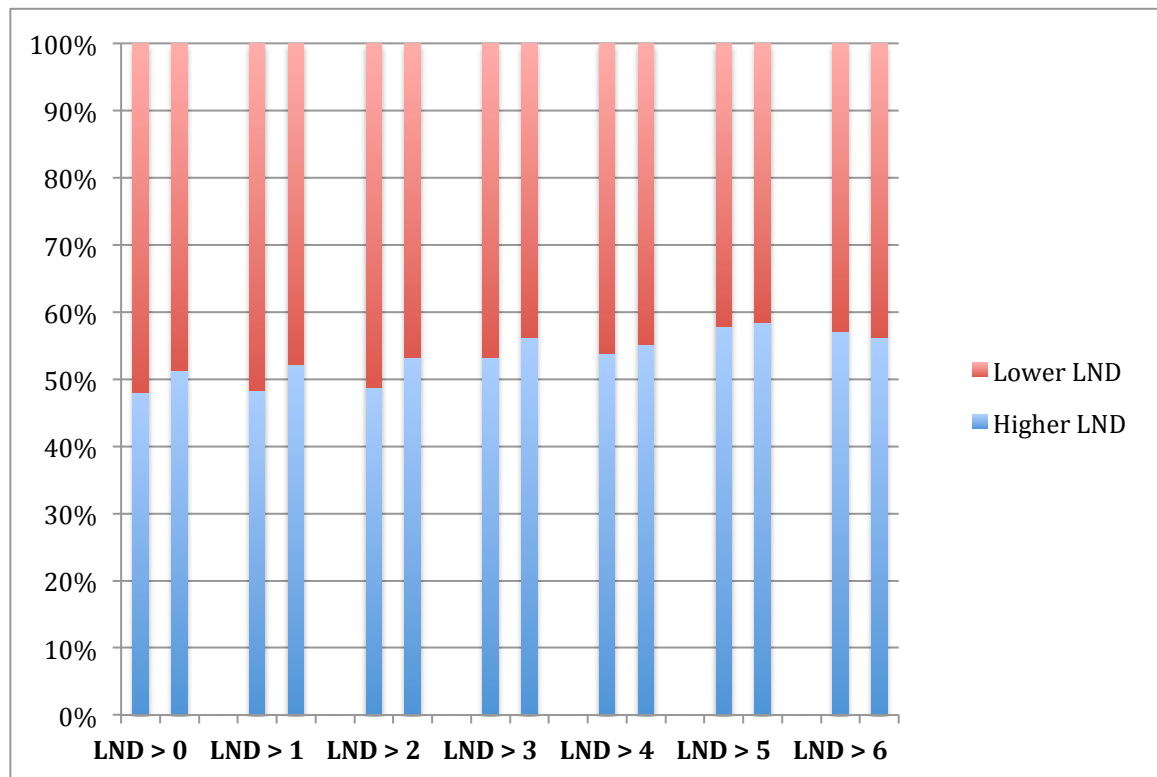


Fig. 21. Effects of LND in Both Experiments

For all threshold levels, except $LND > 6$, there is a larger bias towards the higher LND item in Experiment 2 compared to Experiment 1. This is as expected: A smaller LND effect was seen when participants were told they were listening to non-words. In addition, the effect of LND is increased when the results are filtered, including only comparisons with large LND differences. It is close to random at $LND > 0$, but approaches 60% once LND differences are greater than 5. The fact that no effect is seen for LND in the logistic regression model may indicate that the effect in Figure 21 is an artifact of grammatical effects. Since LND will correlate with grammaticality, the two are not completely independent; the model takes this into account though.

Vowel quality crossed with tone was added to the model for comparisons varying tone, with no significant effect discovered for any of the vowels, nor for their interactions with tone. In comparisons varying manner, it was not possible to cross vowel quality with tone due to a lack of stimuli with all combinations; however, nesting vowel quality simply yielded a significant effect for the vowel [u] as compared to the baseline vowel [a] ($\beta = 1.100$, $z = 0.446$, $p < 0.05$). This effect indicates a preference across participants for voiced and unaspirated onsets with the vowel [u]. The mean response for voiced onsets was 0.738; the mean response for unaspirated onsets was 0.531. Inclusion of vowel quality did not affect the main effects for high and rising tone, however the intercept term was no longer significant ($\beta = 0.019$, $z = 0.049$, $p = 0.961$). This result implies that the result where voiced-low and unaspirated-low sequences were preferred to aspirated-low sequences was an artifact, with the real explanation due to a vowel quality effect.

However, there are two reasons that suggest this is not the case. First, the mean responses differ substantially between voiced (0.738) and unaspirated stops (0.531). This

suggests that any effect of [u] does not extend generally to the feature [+CG], but is instead a more specific interaction with the feature [+voice] (recall in Experiment 2 that low tone was preferred with both voiced and unaspirated onsets). Second, the model with vowel quality included has a higher Bayesian Information Criterion (2175 vs. 2131), indicating that the basic model has a higher likelihood. This indicates that the increased power that comes with including vowel quality in the model does not result in a sufficiently better fit than the basic model. As a result, it is concluded that vowel quality does not introduce a confound into the responses.

Finally, place of articulation is nested simply into the basic logistic regression model, and it is found that no significant effect is seen for place of articulation in both comparisons varying manner and tone. Therefore, the main effects reported above do not include confounds from any additional factors.

4.3.2.4 Assessing the Effect of Loan vs. Native Interpretation

The results for three of the four onset-tone sequences tested in Experiments 1 and 2 suggest that there are distinct loan and native strata in Thai. Results for both experiments are summarized together in Figure 22 below.

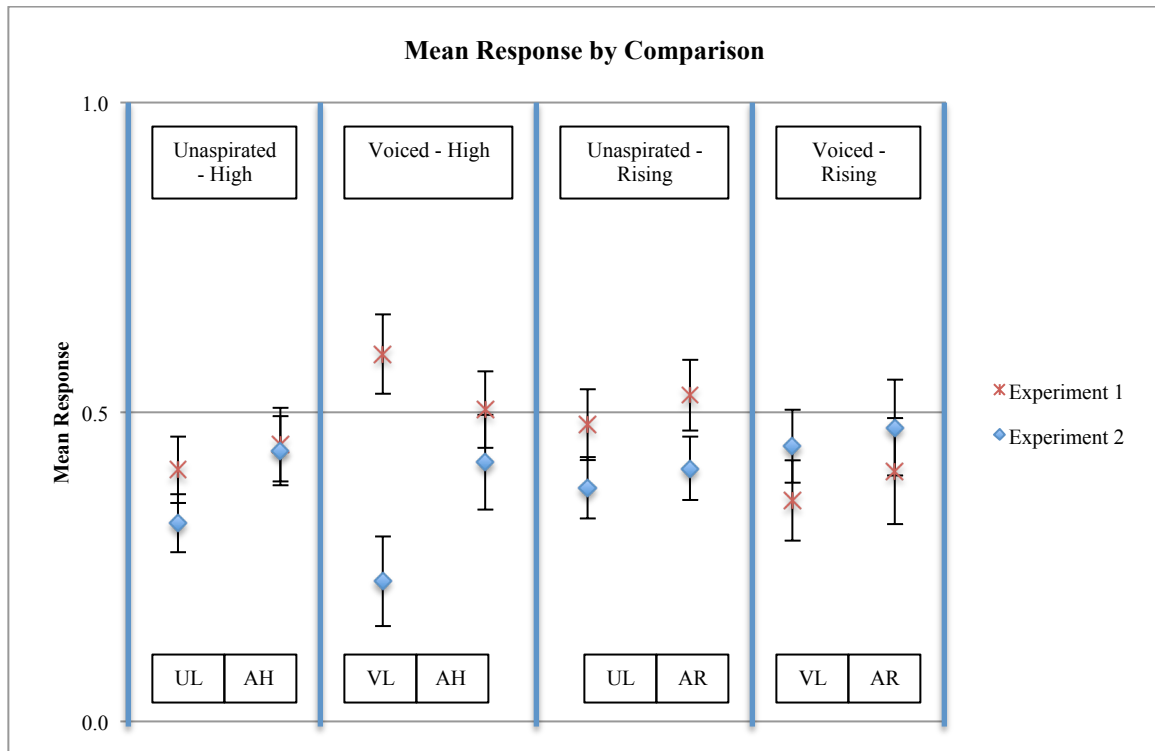


Fig. 22. Experiment 1 & 2 Results – Test Comparisons

Responses in the *voiced-rising* comparisons appear to contradict Ito & Mester's (1995, 1999, 2001) theory, since the difference in response means between experiments is in the opposite direction: The *voiced-rising* sequence was unexpectedly dispreferred to a greater degree in Experiment 1 than in Experiment 2. In Experiment 1, the *voiced-rising* sequence was the only sequence to be significantly dispreferred; however, in Experiment 2, it is the sequence that is *least* dispreferred.

A logistic regression analysis was performed to compare results across experiments. The prediction is that if a difference in grammaticality exists, the loan stratum will allow a given onset-tone sequence and the native stratum will not. The weakest result consistent with Ito & Mester's theory is that at least there should not be any sequence dispreferred to a greater degree in loans than in native items (the *voiced-rising* sequence will be the

relevant test here). If a difference in grammaticality does exist, there should be an interaction between experiment and tone in comparisons varying manner. Likewise, in comparisons varying tone, there should be a significant interaction between experiment and manner. The weakest version of the theory is consistent with a lack of such a significant interaction though. The lack of an interaction would indicate that we cannot reject the null hypothesis that the onset-tone sequences in question are treated as equally grammatical in the loan and native strata. The next two subsections separate the results for comparisons varying manner from those for comparisons varying tone, treating each in turn.

4.3.2.4.1 Comparisons Varying Manner

The logistic regression results between experiments are summarized in Table 30 below for comparisons varying manner.

Table 30

Logistic Regression – Between Experiments (Comparisons Varying Manner)

* - indicates significance with $p < 0.05$

Manner Varying – Voiced/Unaspirated (1) – Aspirated (0)	Estimate	Std. Error	z-value	p-value
* Intercept (Unaspirated vs. Aspirated, L tone, Experiment 2)	0.420	0.133	3.162	0.002
* Experiment (Exp. 1)	−0.392	0.196	−2.000	0.046
* Tone (H)	−0.677	0.159	−4.263	0.000
* Tone (R)	−0.796	0.153	−5.188	0.000
Manner (Voiced vs. Aspirated)	0.085	0.180	0.471	0.637
Experiment (Exp. 1): Tone (H)	0.433	0.233	1.858	0.063
* Experiment (Exp. 1): Tone (R)	0.879	0.226	3.888	0.000
Experiment (Exp. 1): Manner (Voiced vs. Aspirated)	0.320	0.263	1.213	0.225
Tone (H): Manner (Voiced vs. Aspirated)	−0.163	0.269	−0.608	0.543
Tone (R): Manner (Voiced vs. Aspirated)	0.190	0.264	0.719	0.472
Experiment (Exp. 1): Tone (H): Manner (V vs. A)	−0.009	0.375	−0.025	0.980
* Experiment (Exp. 1): Tone (R): Manner (V vs. A)	−1.099	0.393	−2.800	0.005

In comparisons varying manner, the fact that no significant interactions existed

between experiment and high tone indicates that the high tone restrictions were not treated differently between experiments, and therefore that they are not treated differently in loan and native strata. While this does not reach significance, a difference is seen in the VH-AH comparison (see Figure 22 above), in the direction expected: In Experiment 2, participants were significantly biased towards the *aspirated-high* sequence. This was not the case in Experiment 1, where they responded at random. Notably, the results do not contradict Ito & Mester's theory since the restriction for English loans (or the lack of one in this case) is still a subset of the restrictions in the native stratum.

Unlike high tone, a significant interaction between experiment and rising tone was discovered. In addition, the interaction between experiment, rising tone and manner was also significant. This latter interaction refers to the apparent flip that occurs between experiments depending on the onset: The *unaspirated-rising* sequence is dispreferred in Experiment 2 but not Experiment 1. The *voiced-rising sequence*, on the other hand is dispreferred in Experiment 1, but not in Experiment 2. The *unaspirated-rising* result is expected if loan strata are more permissive; however, the *voiced-rising* result is not expected. Instead, participants in Experiment 2 should disprefer the voiced-rising sequence at least as much as those in Experiment 1. This is not the case though and is an apparent contradiction to Ito & Mester's theory.

In addition to effects of experiment, some effects held generally, across both experiments. One such effect was a significant positive effect for the intercept. This effect indicates that participants preferred unaspirated onsets more often than aspirated onsets with low tone (UL-AL comparison in Figure 22 above). However, the extent of this effect differed between experiments: The negative coefficient for "Experiment"

means that significantly fewer unaspirated responses were given in Experiment 1. This is evident in Figure 22 above, where we see fewer unaspirated-low choices in the UL-AL comparison in Experiment 2 than in Experiment 2. While there was a general preference for *voiced-low* sequences in both experiments, the *unaspirated-low* preference surfaced only in Experiment 2. This implies that in the loan stratum, there was a more specific markedness constraint acting only on voiced stops; in the native stratum a more general constraint is active that acts on all [+constricted glottis] consonants. Therefore, not only do stratum differences exist in overt grammatical restrictions, but there is also evidence for stratum differences affecting preferences between grammatical onset-tone sequences. It is difficult to ascribe this finding to anything other than a phonological grammar.

Significant effects across both experiments were also seen for tone: The negative coefficients for Tone (H) and Tone (R) indicate that participants prefer aspirated onsets in comparisons with high and rising tone more often than in comparisons with low tone. This is consistent with the onset-tone restrictions existing in both loan and native grammars. However, when the results for each experiment were treated separately, this general effect was discovered only in Experiment 2, and not in Experiment 1, suggesting that the grammatical restriction is significant in Experiment 2 and not Experiment 1.

4.3.2.4.2 Comparisons Varying Tone

Turning now to comparisons varying tone, summarized in Table 31 below, two significant interactions with experiment were discovered in addition to three effects seen across both experiments.

Table 31
Logistic Regression – Between Experiments (Comparisons Varying Tone)

Tone Varying – H/R tone (1) – L tone (0)	Estimate	Std. Error	z-value	p-value
Intercept (Aspirated, H vs. L tone, Experiment 2)	−0.080	0.145	−0.555	0.579
Experiment (Exp. 1)	0.133	0.211	0.633	0.527
Tone (R vs. L)	0.273	0.165	1.650	0.099
** Manner (Unaspirated)	−0.713	0.155	−4.584	0.000
** Manner (Voiced)	−1.203	0.240	−5.014	0.000
Experiment (Exp. 1): Tone (R vs. L)	−0.398	0.242	−1.646	0.100
Experiment (Exp. 1): Manner (Unaspirated)	0.276	0.224	1.231	0.218
** Experiment (Exp. 1): Manner (Voiced)	1.536	0.299	5.138	0.000
Tone (R vs. L): Manner (Unaspirated)	−0.010	0.227	−0.044	0.965
** Tone (R vs. L): Manner (Voiced)	0.770	0.297	2.589	0.010
Experiment (Exp. 1): Tone (R vs. L): Manner (Unaspirated)	0.436	0.331	1.318	0.188
** Experiment (Exp. 1): Tone (R vs. L): Manner (Voiced)	−1.629	0.399	−4.080	0.000

First, a significant interaction between experiment and voiced manner was discovered. This means that a different response pattern existed in comparisons with voiced stops compared to aspirated stops between the two experiments. The positive sign on the coefficient indicates that in Experiment 1, more “1” (high/rising tone) choices were made with voiced stops than in Experiment 2. Second, a significant interaction between voiced stop, experiment and tone was discovered. This result indicates a significant difference in the VH-VL comparison between experiments that cannot be explained by more general effects of voiced stops or high tone. In loan words, *voiced-high* sequences are tolerated and even preferred; in native items *voiced-high* sequences are ungrammatical. This difference was the most significant difference seen between the two experiments, and can be clearly seen in Figure 22 above in the VH-VL comparison. The positive sign on the interaction term for experiment and manner accounts for this preference, attributing it to a general preference for high (and rising) tone with voiced stops in Experiment 1. The negative sign on the interaction term between experiment, tone and voiced manner indicates that there were significantly fewer responses for the

voiced-rising sequence in Experiment 1 than Experiment 2.

No significant interactions between unaspirated manner and experiment were seen. While this interaction was not significant, it is clear that the mean responses for the *unaspirated-rising* and the *unaspirated-high* sequences were shifted towards the low-tone alternative in both cases in Experiment 2. This shift is in the direction expected: The *unaspirated-high* and *unaspirated-rising* sequences are dispreferred to a greater extent, though not significantly so in Experiment 2.

Finally, significant effects were discovered for unaspirated and for voiced manner, independent of experiment. The negative coefficients indicate that a consistent preference for low tone over high tone with both unaspirated and voiced stops was seen across both experiments. Just as in the comparisons varying manner, this indicates that the onset-tone restrictions are present in both experiments. However, when treated separately, only the results in Experiment 2 reached significance, indicating that there was in fact a difference between the two experiments. A third significant effect was seen in the interaction between tone and voiced manner across both experiments. The positive coefficient indicates that there is a stronger dispreference for high tone than for rising tone in comparisons with voiced stop onsets.

4.3.2.5 Conclusion

In conclusion, Experiment 2 showed that the four onset-tone restrictions are found to be significant only in the Thai native stratum. Experiment 1 showed that three of the four restrictions were relaxed. Of these, there was no evidence of an *unaspirated-rising* restriction, and only marginal evidence of the *unaspirated-high* restriction. The *voiced-*

high restriction was not only absent in the loan stratum, but *voiced-high* sequences were actually preferred in comparisons with *voiced-low* sequences. The only exception was the voiced-rising sequence, which was actually dispreferred to a greater extent in Experiment 1. This suggests a grammatical restriction for *voiced-rising* sequences in the loan stratum that does not exist in the native stratum, contra Ito & Mester.

Finally, an unexpected effect was seen in both experiments where participants preferred voiced onsets to aspirated onsets with low tone, despite the fact that both sequences are equally attested and presumably grammatical. This result is in accordance with findings in other languages where preferences were displayed that cannot be learned from language experience, suggesting that grammar is playing a role instead (Frisch & Zawaydeh 2001; Berent et al. 2007; Coetzee 2008, 2009). In Experiment 2, a preference was seen for unaspirated onsets with low tone in addition. This observation is thought to be due to a markedness constraint where low tone and [+constricted glottis] consonants have an affinity for each other. The difference between experiments is consistent with a loan stratum that is more permissive: The native stratum includes a general constraint where all [+constricted glottis] consonants are preferred with low tone; the loan stratum involves a more specific constraint involving a preference with [+voice] consonants and low tone. The results from both experiments are summarized in Table 32 below.

Table 32
Summary of Results & Predictions Across Experiments

	Stimulus 1	Stimulus 2	Predicted Preference in Native Stratum (Ito & Mester's Theory)	Experiment 1 Results		Experiment 2 Results	
Test Comparisons	UH	UL	UL	UL	✓	UL	✓
	UH	AH	AH	AH (n.s.)	✓	AH (n.s.)	✓
	VH	VL	VL	VH	✗	VL	✓
	VH	AH	AH	Same	✓	AH	✓
	UR	UL	UL	Same	✓	UL	✓
	UR	AR	AR	Same	✓	AR	✓
	VR	VL	VL	VL	✓	VL	✓
	VR	AR	AR	AR	✓	Same	✗
Control Comparisons	AH	AL	Same	Same	✓	Same	✓
	UL	AL	Same	Same	✓	UL	✗
	AR	AL	Same	Same	✓	Same	✓
	VL	AL	Same	VL	✗	VL	✗

4.3.3 Discussion

While the regression analysis confirms that within each comparison type, the same preferences exist, there is a notable difference between the effects seen in comparisons with tone varying and comparisons with manner varying. Responses in the comparisons varying tone tend to be more significant in the direction expected whereas responses in the comparisons varying manner usually involve a less pronounced effect, if any is seen at all. This is especially pronounced in the high-tone comparisons. In fact, all significant differences seen (in either direction and in both experiments) are stronger in comparisons varying tone than they are in corresponding comparisons varying manner.

As an explanation for the discrepancy between comparisons varying manner and comparisons varying tone, it is posited that a greater chance of misperception of stimuli exists in the former relative to the latter. Additionally a single explanation is offered for two unexpected results in Experiment 2. A constraint that encodes an affinity between

[+CG] and low tone can potentially explain the fact that the rising tone restrictions elicit less pronounced responses and at the same time explain the fact that *voiced-low* and *unaspirated-low* sequences are preferred to *aspirated-low* sequences.

4.3.3.1 Tone Confusion

Tones in Thai may be difficult for people to recognize in isolation, taken out of connected speech. Zsiga & Nitisaroj (2007) noted that excised syllables led to higher error rates in identification. The current study uses a list format to elicit stimuli, so while they are not excised from connected speech, it could be that they still lack certain queues present in connected speech (although cf. Abramson 1962, where it is reported that citation forms are identified with minimal errors). Misperception of tones, if it happens at all, will be more likely to occur in comparisons where tone is constant and manner is varied, as a result. In comparisons varying tone, participants are exposed to two different tones in the speaker's range, thus potentially disambiguating those tones in that comparison. In a post-experiment questionnaire conducted in Experiment 2, participants were asked to identify the tones in 14 tokens used in the experiment. The results of this questionnaire are summarized below in Table 33, across all participants.

Table 33
Perception of Tones

	L (Perceived)	H (Perceived)	R (Perceived)	F (Perceived)	M (Perceived)
L (Actual)	66	0	2	0	7
H (Actual)	0	34	10	1	0
R (Actual)	0	6	37	2	0

Of particular importance here is the tendency for high and rising tone to be

confused.³⁸ These tones are phonetically similar in that they both consist of rising contours and therefore, they may be more likely to be confused for each other. Notably, 10 of the 45 high tone tokens were mistaken for rising tone. Likewise 6 of the 45 rising tone tokens were mistaken for high tone. As a result, in comparisons varying manner, it is relatively more likely that the high tone stimuli may be mistaken for rising tone stimuli. In comparisons varying tone, the low-tone stimulus item should make misperception of high and rising tone less likely, since the low tone will act as a benchmark for where a rising tone starts (Low) as opposed to where a high tone starts (Mid). Since the rising tone restrictions are generally less significant than the high tone restrictions (in Experiment 2 anyway), it might be the case that the less significant response means in the VH-AH and UH-AH comparisons are due to more frequent misperception of high tone as rising tone. In fact, the results in Figure 22 show that VH-AH and UH-AH align fairly closely with the corresponding responses for rising tone. This effect is discussed again in the following chapter, which seeks to relate the Thai grammar to the finer-grained distinctions seen in the results of the experiment.

4.3.3.2 *Interaction of Weighted Markedness Constraints*

In this subsection, the preliminaries are outlined for a task-model that may help to explain two of the finer-grained results reported above: First, there was a significant preference for *voiced-low* and *unaspirated-low* sequences in comparison to *aspirated-low* sequences. Second, there was a stronger response bias in comparisons with high tone than in rising tone comparisons. These observations can be explained by appealing to lower-

³⁸ In contrast, Zsiga & Nitisoroj 2007 found that rising tone was more often confused with low tone. This may be a function of how the individual speakers pronounced these tones in each study however, rather than a fact about perception of tones in Thai, more generally.

ranked markedness constraints that do not figure in the grammar itself, but may be relevant in this particular task. This proposal here seeks to map information in the ranking required to learn the Thai grammar to a task-specific model where constraints are assigned weights and affect responses accordingly.³⁹ This model is outlined with two constraints here, but a more detailed implementation can be found in Chapter 5.

A constraint, *[+CG]-high⁴⁰ is the one responsible for the main effect. However, there is evidence that lower-ranked constraints can also contribute to judgments. If these constraints were not strictly ranked but instead interacted additively, then this provides a way to explain the discrepancy seen between high and rising tone comparisons and the *voiced-low/unaspirated-low* preference in one stroke. While the rising tone sequences also violate *[+CG]-high due to the second mora being linked to H tone, they actually satisfy a second constraint, [+CG]-low. The two constraints involved in the competition being described here are summarized below in (15).

- (15) i. *[CG]-high: Assign one violation for each [+CG] segment that precedes an H tone (at any distance), within the syllable.⁴¹
- ii. [+CG]-low: Assign one violation for each [+CG] segment that does not immediately precede an L tone, within the syllable.⁴²

Consider the VR-VL comparison. The *voiced-rising* sequence satisfies [+CG]-low

³⁹ This idea is similar to Coetzee's (2004) rank-ordered EVAL.

⁴⁰ This constraint is used here as a means of illustration. Chapter 5 shows that the actual version of this constraint is one that bans a rising contour following [+CG] onsets.

⁴¹ In the phonological account in the next chapter, this constraint will be altered to *[+CG]-[H]_μ2. But this does not affect the argument here.

⁴² Notably, this constraint is an onset-oriented version of Morén & Zsiga's L Tone → Coda constraint, and may perhaps be unified under a single constraint. This option is not explored here however.

tone since rising tone (LH) places an L tone adjacent to a [+CG] onset. On the other hand, the *voiced-low* (ML) sequence does not place an L tone immediately adjacent to a [+CG] onset. Therefore, the *voiced-low* sequence violates [+CG]-low. Now consider the VH-VL comparison. In this case, both sequences violate [+CG]-low once because neither have a [+CG] segment that is immediately adjacent to an L tone. This distinguishes the rising tone sequences from the high tone sequences in that we have identified a constraint that actually prefers a *voiced-rising* sequence to its competitor, but does not make any such preference in the VH-VL comparison. If the influence of [+CG]-low were to be incorporated into a task model that applies information available from the grammar, this can potentially explain the results on a finer-grained level.

Importantly, this departs from usual assumptions on how constraint interactions behave, where Optimality Theoretic constraints are strictly ranked with respect to one another (Prince & Smolensky 1993/2004). In standard OT, additivity among different constraints can never happen; constraints are strictly ranked and as a result, higher-ranked constraints obliterate any effect that lower-ranked constraints may have. However, the task in this experiment is not necessarily typical for the everyday language user. Importantly, faithfulness constraints do not come into play in this task; participants hear two non-word stimuli and are asked to choose which one sounds more like it could be a word of Thai. The fact that faithfulness is not involved and that they are not dealing with “speaking the Thai language” in the usual sense, changes the way in which they use their grammar. In this task, they would weigh competing markedness constraints directly in order to make their decision.

The proposal here is that relations between markedness constraints are preserved but

via a weighting mechanism, since absolute ungrammaticality via markedness-faithfulness relations is irrelevant. In such a system, it is interesting to observe how markedness constraints that are not crucially ranked in the grammar would be weighted. In this case, the [+CG]-low tone is such a constraint, as it plays no crucial role in accounting for the surface pattern of consonant-tone interaction in Thai (see Chapter 5 for more details). In the case here, [+CG]-low is apparently subordinated to *[+CG]-high. The *[+CG]-high constraint is weighted more heavily, as can be seen in the UR-AR result in Figure 22 above, where these two constraints act alone in opposition, and yet the *aspirated-rising* sequence is preferred. That the *[+CG]-high constraint is weighted more heavily is a reflection of the categorical grammar: The *[+CG]-high constraint plays an important role in explaining why the onset-tone sequences are ungrammatical and must be ranked above some faithfulness constraint, whereas the [+CG]-low does not. The categorical grammar interacts with this system in that markedness constraints that are crucially ranked with respect to each other in order to account for the ungrammaticality of the four onset-tone restrictions should have this relation preserved (i.e. a higher ranked constraint must have a higher weighting than a lower ranked constraint). This prediction is tested in the following chapter.

4.3.3.3 *The Voiced-Rising Sequence Flip*

One result that is not easily accounted for concerns the findings for the *voiced-rising* sequence in the two experiments. The *voiced-rising* dispreference was unexpectedly more significant in Experiment 1. This seems to indicate that the loan stratum includes a restriction (*[+voice]-LH) that is not present in the native stratum. However, there is still

some weak evidence that the voiced-rising sequence is dispreferred in the native stratum, since the VR-VL comparison was very nearly significantly biased towards the voiced-low option. The fact that participants' responses in the VR-AR comparison was at random might then be an instance of the [+voice]-low constraint influencing responses, as described in the previous subsection.

Once the voiced-rising sequence is taken to be ungrammatical in both strata, all that remains to explain is the shift in responses. The explanation offered here is that the loan stratum involves a relaxing of the other three restrictions, leaving the voiced-rising restriction as the only onset-tone restriction present in the loan stratum. As a result, participants in Experiment 1 may be emphasizing its presence to a greater degree. If among all the experimental stimuli they hear, there is one that they find to be ungrammatical, they will be more likely to key on it than they would if that restriction were mixed in with three others, as in Experiment 2. Additionally, recall that in Experiment 1, only the *voiced-low*, but not the *unaspirated-low* sequence was preferred to the *aspirated-low* sequence. This indicates that the [+CG]-low constraint (for whatever reason) was not exerting itself in Experiment 1. As a result, we would expect the influence of the *[+CG]-H constraint to be stronger in Experiment 1 for rising tone comparisons. The responses for the voiced-rising comparisons did exactly this. The responses for the unaspirated-rising comparisons were at random, however. This set of observations suggests that voiced-rising sequences are treated as equally ungrammatical in both experiments.

Making this assumption allows a picture of the native and loan strata in Thai that adheres to the implicational relation posited by Ito & Mester (1995, 1999, 2001): The

loan stratum involves a single specific markedness constraint (*[+voi]-LH) that outranks the relevant faithfulness constraint, whereas the native stratum involves a more general version (*[+CG]-H). This situation is represented schematically in (16).

$$(16) \quad *[\text{+voi}]\text{-LH} \gg \text{Faith}_{\text{Loan}} \gg *[\text{+CG}]\text{-H} \gg \text{Faith}_{\text{Native}}$$

An OT-based phonological analysis built around this basic ranking scheme is outlined in the following chapter. Importantly, the results of this experiment establish that not only high tone, but also rising tone is ungrammatical following [+constricted glottis] onset consonants in unchecked syllables. An updated version of the consonant-tone restrictions in Thai is given below in Table 34, based on the findings of this chapter.

Table 34
Consonant-Tone Restrictions in Thai

	Onset	Mid Tone	Low Tone	Falling Tone	High Tone	Rising Tone
Unchecked	C _{else}	Attested	Attested	Attested	Attested	Attested
	T	Attested	Attested	Attested	Unattested	Unattested
	D	Attested	Attested	Attested	Unattested	Unattested
Checked	C _{else} & long V	Unattested	Attested	Attested	Unattested	Unattested
	C _{else} & short V	Unattested	Attested	Unattested	Attested	Unattested
	T	Unattested	Attested	Unattested	Unattested	Unattested
	D	Unattested	Attested	Unattested	Unattested	Unattested

4.4 Conclusion

This chapter has presented a pair of experiments that showed all four onset-tone restrictions are psychologically real and should be treated as part of the Thai grammar,

rather than accidental gaps. Unlike the native stratum, only the *voiced-rising* sequence is deemed to be ungrammatical in the loan stratum. This finding is in agreement with Ito & Mester (1995, 1999, 2001), who claim that loan strata are more permissive than native strata cross-linguistically.

Additionally, that participants exhibited preferences between attested onset-tone sequences implies the existence of markedness constraints that cannot be learned based on language experience in Thai. Specifically, *voiced-low* and *unaspirated-low* sequences are preferred over *aspirated-low* sequences, even though all three sequences are attested in Thai. This preference is in accordance with theories of consonant-tone interaction (Bradshaw 1998; Lee 2008; Tang 2008), where both voicing and glottal constriction in obstruents are found to have an affinity for low tone, cross-linguistically. This result establishes the presence of markedness constraints that may be innate, and not acquired as part of language acquisition.

Finally, the results in the two experiments can be explained with greater accuracy if stimuli pairs are judged based on competition between weighted markedness constraints, rather than the usual strictly ranked versions. Three results in particular can be unified under a single explanation that involves interaction between two markedness constraints. First, the presence of a constraint [+CG]-low, where low tone requires a preceding [+CG] consonant, is implied by the *voiced-low* and *unaspirated-low* preferences. Next, the fact that comparisons varying tone tend to be more strongly biased away from the ungrammatical onset-tone sequence than in comparisons varying manner can be explained also. In comparisons varying manner, there is a greater chance for tonal confusion and thus these comparisons involve less significantly biased response means.

Finally, the tendency for rising tone dispreferences to be less pronounced than those for high tone is also explained in the same way. Since rising tone contains both L and H tones, the [+CG]-low constraint is not actually violated by *unaspirated-rising* and *voiced-rising* sequences. As a result, their added effect is not seen in the rising tone comparisons, unlike the high tone comparison. An OT account as well as a systematic approach to weighted markedness and how it may interact with an actual categorical grammar is the topic of the following chapter.

Chapter 5 – A Phonological Account of Consonant-Tone Interaction in Thai

5.1 Introduction

This chapter presents a phonological account that explains the empirical facts for consonant-tone interaction summarized in the previous three chapters. The phonological account outlined here extends the account of coda-tone interaction of Morén & Zsiga (2006) to encompass the onset-tone interaction as well. It departs from other accounts of onset-tone interaction in Thai (Ruangjaroon 2006; Lee 2008). In these other accounts, only high tone is taken to be ungrammatical following [+CG] onsets. The present account differs from these previous accounts in that it assumes there is a rising-tone restriction in unchecked syllables as well, based on the findings in Chapters 2 and 4. Ruangjaroon's (2006) and Lee's (2008) accounts rely on the fact that the onset in question is adjacent to the tone with which it interacts. Instead, it is argued here that the consonant-tone interaction cannot be local, once the rising tone restriction is included. This follows from the fact that falling tone (HL) can occur following [+CG] onsets in Thai, but that high (assumed to be a Mid-High sequence, following Morén & Zsiga 2006)⁴³ and rising tone (LH) cannot. This situation is illustrated in (17) below.

⁴³ Ruangjaroon (2006) and Lee (2008) assume that H tone is linked to both moras in Thai high tone, unlike the representation of Morén & Zsiga (2006) shown in (17b). Even if high tone involves an H shared between two moras, the argument here applies anyway for rising and falling tone: When the H tone is only linked to the second mora (as in 17c), the sequence is ungrammatical; when it is only linked to the first mora (as in 17a), it is grammatical.

(17) Locality in Consonant-Tone Interaction in Thai Unchecked Syllables

a. Falling Tone	b. High Tone	c. Rising Tone
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> H μ C_[+CG] V </div> <div style="text-align: center;"> L μ V </div> </div>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> μ C_[+CG] V </div> <div style="text-align: center;"> H μ V </div> </div>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> L μ C_[+CG] V </div> <div style="text-align: center;"> H μ V </div> </div>
Grammatical	Ungrammatical	

The two ungrammatical sequences share a common phonetic characteristic: They both have *late* H-tone targets, a fact that is reflected in the representations shown in (17). On the other hand, the falling-tone sequence involves an early H-tone target. If adjacency is evaluated based on the linear order of the moras with respect to the onset consonant⁴⁴, then the falling-tone sequence is the only one where the H is strictly adjacent to the [+CG] onset consonant. Yet, this is the only sequence involving an H tone that is grammatical. This situation can only be resolved under an analysis where locality is irrelevant. As a result, it is argued that the onset-tone restrictions in Thai involve a sequence of a [+CG] onset followed by an H tone linked to the second mora in that syllable. A markedness constraint $*[+CG]-[H]\mu_2$ ⁴⁵ is introduced that is violated once per syllable whenever a [+CG] onset consonant occurs within a syllable whose second mora is linked to an H tone (following Morén & Zsiga (2006), it is assumed that all syllables in Thai are bimoraic). The constraint, $*[+CG]-[H]\mu_2$, is argued to be motivated in part by a

⁴⁴ Notably, adjacency may also be evaluated on the autosegmental tier. In this case, the prediction is that high tone (17b) should be grammatical, just like falling tone (17a), since there is no intervening tone between the H autosegment and the [+CG] onset. The fact that high and rising tone are both ungrammatical suggests that this autosegmental adjacency is irrelevant. Instead, only the tone linked to the second mora is relevant.

⁴⁵ The ‘X’ linked to the first mora denotes the fact that the configuration is blind to the tonal content of the first mora. It can be linked to an H, an L or it can be unlinked to any tone. It can even be linked to the same H tone that is linked to the second mora. The key point is that the second mora is linked to an H tone.

universal tendency for pitch targets to be realized late in syllables (Cutler & Chen 1997; Xu 1999, 2004). The second mora can thus be seen as carrying the “head tone” of the syllable, and as such it is the relevant location in a constraint banning high tone with [+CG] onsets. This situation is illustrated below in (18).

(18) The Ungrammatical Onset-Tone Sequence in Thai Unchecked Syllables
 (*[+CG]-[H]μ₂)

	X	H	Autosegmental Tone Tier
	μ	μ	Mora
C _[+CG]	V	V	Segmental Tier

This account improves upon previous accounts of onset-tone interaction by Lee (2008, 2011) and Ruangjaroon (2006) in two major ways. First, as mentioned, it accounts for the previously undocumented rising-tone ban. Second, it does not require any markedness constraint banning mid tone with [+CG] codas, like the one used in Lee’s (2008, 2011) analysis. Following Morén & Zsiga (2006), mid tone is treated here as a mora that is not linked to any tone (only H and L tone autosegments exist); as such, no constraint can refer to mid tone.

This analysis also explains the differences between the loan and native strata, splitting faithfulness constraints, which are relative to either stratum, following Ito & Mester (1995, 1999, 2001). Finally, the finer-grained results of the judgment experiments in Chapter 4 are explained under a task-specific model of competing weighted markedness constraints, similar to the rank-ordered EVAL of Coetzee (2004). The task, which involved comparison of non-word stimuli, is accessing the grammar but not via a

mapping from an input, since phonological inputs, and therefore faithfulness constraints are irrelevant in the task. Instead, it is argued that the task involves a weighted comparison of markedness constraints. The model is based on a numerical weighting system that comes from the grammar itself, thus providing a way to explain the finer-grained results by appealing to a task-specific model.

5.2 *An Optimality-Theoretic Account of Consonant-Tone Interaction in Thai*

5.2.1 *Assumptions on Moraic Structure and Tone in Thai*

This section describes the moraic representation of Morén & Zsiga (2006), which is adopted here. Morén & Zsiga assume that tones are right-aligned in Thai, based on phonetic facts. High tone is phonetically rising (mid-to-high) and low tone is phonetically falling (mid-to-low). Therefore, the pitch targets are late, and it is argued that in a phonology that is faithful to the phonetics to the greatest extent possible, the tonal autosegments should be right-aligned. Their representations are shown in (19) below.

(19) Representation for the Tonal System of Thai (Morén & Zsiga 2006)

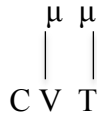
Mid	High	Low	Falling	Rising
	H	L	H L	L H
μ μ	μ μ	μ μ	μ μ	μ μ

It is assumed that all Thai syllables are bimoraic. This is because there are no open syllables with short vowels in Thai; syllables with short vowels require a coda. Codas are then moraic in Thai. In syllables with long vowels and codas (CVVC), the second mora is linked to the vowel and the coda simultaneously. As a result, vowel length is contrastive

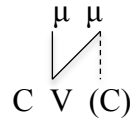
based on whether the second mora is linked to the vowel or not. This situation is illustrated schematically in (20) below.

(20) Vowel Length and Moraicity in Thai

a. Short Vowel “CVT”



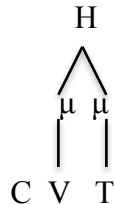
b. Long Vowel “CVV(C)”



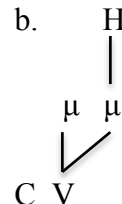
In syllables with long vowels, the representations in (19) straightforwardly capture the fact that H and L tone involve phonetic contours. However, they are potentially problematic in CVT syllables, where only a single moraic vocalic segment is present. Morén & Zsiga assume that CVT syllables with high tone are represented with a single H autosegment associated to both moras (Morén & Zsiga 2006:150 ex. 41c). This is shown in (21) below, using CVV syllables to represent all unchecked syllables. The same representation for short vowels is assumed here.

(21) M & Z’s (2006) Representation for High Tone in CVT and CVV Syllables

a.



b.



Given a desire to treat phonetic facts transparently in the phonology, this predicts a difference in the phonetic realization of high tone between checked CVT syllables and unchecked syllables, where the presence of two vocalic moraic segments will allow a

tonal rise. Specifically, the CVT syllable should be a level high tone (or at least involve a very early and steep rise), whereas CVV syllables should be pronounced with a mid-to-high rise. However, this is not the case. High tone is similarly rising in CVT and CVV syllables (Morén & Zsiga 2006:131 fig. 4). Likewise, the phonetic representation of falling tone includes a rise in pitch over the first part of the vowel (Morén & Zsiga 2006:131 fig. 4). These two facts would follow straightforwardly if the H autosegment is itself realized as a phonetic rise. Therefore, for these reasons, it is tempting to adopt the representation in (21a) for *all* high-tone syllables. This is the representation adopted by Ruangjaroon (2006) and Lee (2008); it is also desirable because it allows for a local relation between the H tone autosegment and the onset consonant.

However, even if the representation shown in (21a) is adopted, it is still necessary to make reference to the second mora. The fact that rising tone, and not falling tone is banned following [+CG] onsets requires such a reference anyway, as shown in (17) above. Rising and high tone share the common property that their H target is on the second mora, under any analysis of H tone. If this is also encoded in the phonology, then it is possible to handle the onset-tone restrictions involving high and rising tone with a single markedness constraint that refers either to a rising tonal contour or an H tone on the second mora.

As a result, the tack taken in this account is one where adjacency at the moraic level is ignored, instead focusing on the rightmost mora following unaspirated and voiced obstruent onsets. This departs from Lee (2008, 2011), whose x-TBU theory posits that tonal autosegments share a link to the first mora and the onset consonant, in order to

explain local interactions between onset consonants and tone. It is argued that, for Thai⁴⁶, there is no reference to adjacency at the moraic level, but that instead co-occurrence restrictions hold between the onset consonant and the rightmost mora.

5.2.2 *Assumptions in GEN*

This section outlines the theory of GEN that is adopted in the Optimality Theoretic account. Rather than tackle all possible constraint interactions, the account here aims to explore input-output mappings that involve changes only on the tonal autosegmental tier. In fact, no segmental changes are explored in the phonological analysis here. The segmental tier and segment-to-mora links are fixed as a property of GEN. Therefore, the representation in (20a) above applies to all candidates with short vowels, both underlying and surface forms; likewise, the representation in (20b) applies to all candidates with long vowels. The only changes allowed between input and output forms involve the tonal tier and/or the links between tones and moras. This is a simplifying assumption made both in the account here and in Morén & Zsiga (2006). It is, in principle, possible to have vowel length and/or segmental changes in response to some of the constraints involved in this analysis. While acknowledging this, the account here assumes a theory of GEN that simplifies the system such that all action occurs in the tonal autosegmental tier and its links with the moraic tier.

Candidates are considered that vary the following characteristics in (22).

⁴⁶ It is predicted that other languages should also display this behavior, where the rightmost mora is the one relevant in consonant-tone interactions with an onset consonant. I do not explore cross-linguistic evidence for this here, but leave this as a question to be addressed in future research.

(22) GEN: Candidate Variation Among Inputs

1. Whether the onset consonant is [+CG, –voice], [+CG, +voice] or not [+CG].
2. Whether the vowel is long or short (assuming the moraic representations in (20) above).
3. Whether there is a coda consonant that is [+CG] or not.

A given candidate will not have any disparities for these characteristics between the input and output. Disparities between input and output only arise in the tonal tier.

As discussed in the previous section, all Thai syllables are bimoraic. For a given mora, there are three possibilities⁴⁷ with respect to its association to the tonal tier, as shown in (23).

(23) GEN: Candidate Variation Within Candidates

1. The mora is linked to an H tone.
2. The mora is linked to an L tone.
3. The mora is not linked to any tone (realized as mid tone, referred to as “M”⁴⁸).

Since each mora is independent, and since each syllable contains exactly two moras, this allows for a total of nine (3 x 3) possible tonally distinct syllables. These tonal

⁴⁷ There are actually more possibilities if multiple tones are allowed to link to a single mora. However, it is assumed that either one tone or no tone is linked to each mora here as a property of GEN. Morén & Zsiga (2006:140 ex. 21) assume a violable but undominated constraint, *[TT]μ that is violated by moras that are linked to multiple tones.

⁴⁸ It is important to note that, here and throughout, although I occasionally refer to toneless moras as “mid” or as “M”, this is only a notation to distinguish them from their fully specified H and L counterparts. The system itself does not and can not refer to a notion of “M” or “mid” in any way. The short-hand representation, “HM” differs from one that is “MH” in that “HM” has a single H tone linked only to the first mora, whereas “MH” has a single H tone linked only to the second mora.

representations are listed as follows in (24), via a short-hand notation that is used in OT Workplace (Prince & Tesar 2013).

(24) Possible Tonal Representations in GEN

1. HH
2. HM
3. HL
4. MH
5. MM
6. ML
7. LH
8. LM
9. LL

However, there is the additional possibility that a single tonal autosegment may be linked to two moras. This allows for two additional representations for the “HH” and “LL” sequences listed above. The “H” that the two moras are linked to in an “HH” sequence may be the same “H”, or it may be two separate instances of an “H” autosegment; the same holds true for an “LL” sequence. As a result, two additional distinct tonal representations are admitted in GEN, shown in (25) below, yielding a total of eleven possible tonal representations.

(25) Tonal Representations in GEN (cont.)

10. H2 (a single “H” autosegment shared between moras)

11. L2 (a single “L” autosegment shared between moras)

These short-hand notations are used in OT Workplace (Prince & Tesar 2013), such that each input considered consists of a competition between eleven candidates. Recall that onset type, vowel length and coda type are all fixed between input and output forms. Therefore, there are more than eleven possible inputs to be considered. In addition to the eleven possible tonal representations, there are three possible onset types, two possible vowel lengths, and two possible coda types, yielding a maximum total of (11 x 3 onsets x 2 lengths x 2 codas) 132 possible inputs that the system. However, Thai does not allow open syllables with short vowels. In addition, there is no constraint in the system that distinguishes between syllables with sonorant codas (CVN/CVVN) and unchecked open syllables with long vowels (CVV). As a result, it is possible to treat syllables with short vowels and sonorant codas and unchecked open syllables with no coda as if they were identical. Therefore the system will assume all syllables with short vowels have [+CG] obstruent codas, thus reducing the total number of inputs to consider by 33 (3 onset types x 11 tonal representations), to 99. The inputs considered are listed in Appendix D, along with the mapping assumed between inputs and outputs for Thai. This mapping is consistent with the mapping used in Morén & Zsiga (2006), but is extended to cover all possible inputs, including those with onset-tone interaction.

5.2.3 *Assumptions on Phonological Features*

Turning now to the constraint that drives consonant-tone interaction, Ruangjaroon (2006) and Lee (2008, 2011) both assume that the feature value [–spread glottis] ([–SG]) defines the class of consonants that are banned preceding H tone, via a constraint banning [–SG] followed by H tone. This assumption correctly separates the unaspirated and voiced obstruents from all other segments. However, Lee notes that Thai is apparently the only language in his cross-linguistic survey of consonant-tone interaction where [–SG] and not [+SG] or [+CG] is active. In Chapter 3, it was established that unaspirated and voiced stops both occur with laryngeal constriction, while aspirated stops do not. This implies that Thai is not actually exceptional, and that the feature [+CG] is the relevant feature in the consonant-tone interaction, just as in other languages in Lee’s survey. Thus, the feature [+CG] is employed throughout, rather than the feature [–SG].

5.2.4 *Coda-Tone Interaction – Morén & Zsiga (2006)*

It is not possible to account for onset-tone interactions in Thai without also addressing the restrictions seen between obstruent codas and tone. To that end, this section provides a summary of the analysis of Morén & Zsiga (2006), whose account will be extended to explain the onset restrictions (see Appendix C for their final constraint ranking). Only the main constraint interactions that account for the coda-tone interaction are summarized here. The reader is referred to Morén & Zsiga (2006) for a more detailed account of the constraints involved. A complete list of the constraints used by Morén & Zsiga and in the present account, along with their definitions, is given in Section 5.2.7.

Their final ranking is shown in Appendix C. The facts regarding coda-tone interaction are repeated in Table 35 below for checked syllables in Thai.

Table 35
Coda-Tone Restrictions in Checked Syllables

V-Length	Mid Tone	Low Tone	Falling Tone	High Tone	Rising Tone
Long V	×	✓	✓	×	×
Short V	×	✓	×	✓	×

Recall that only low tone is allowed in all checked syllables. In addition, high tone can surface, but only in syllables with short vowels; in syllables with long vowels, falling tone surfaces instead. Mid and rising tones are completely unattested in checked syllables.

Notably, the moraic representations of Morén & Zsigá (2006), as shown in (19) above treat mid tone as toneless. As a result, no constraint can explicitly refer to mid tone. This treatment of mid tone is based on cross-linguistic observations of mid tone being inactive or less marked than high and low tone (Yip 2002). While mid tone is often treated as less marked, this creates a paradox in Thai, noted by Morén & Zsigá, since mid tone is actually unattested in checked syllables, while low, falling and high tone are attested. This paradox is explained via the presence of a markedness constraint that requires an L tone to be linked to codas in checked syllables (Morén & Zsigá 2006:143 ex. 31):

- (26) C.G.Coda \rightarrow L: Constricted glottis coda segments must be associated with low tone.

This analysis assumes that codas are [+constricted glottis] and that they are linked to moras (and therefore also to tone). There is a range of evidence that final consonants in Thai and other languages are commonly glottalized. Maddieson (1977) notes that voiceless codas allow for reinterpretation as a laryngeal segment. A correlation between glottalization in codas and low tone is seen in both English (Pierrehumbert 1995; Huffman 1998) and Thai (Abramson 1962), a fact that Morén & Zsiga use to ground the constraint in (26) above.

The constraint in (26) solves the markedness paradox by requiring the presence of L tone, even if it is not present underlyingly. By ranking C.G.Coda → L above *[L], toneless inputs will surface with low tone, rather than mid tone in checked syllables. Faithfulness constraints (which are all of the MAX variety here) do not come into play, since the input does not contain any tone⁴⁹. This is shown in tableau (27) below, (from Morén & Zsiga 2006:146 ex. 32).

(27) Mid tone maps to low tone in checked syllables

	/la:k/ ‘various’	C.G.Coda-->L	*[L]
a.	L μμ ∨ l a k ²		*
b.	μμ ∨ l a k ²	*!	

⁴⁹ The only faithfulness constraint that would come into play is DEP[Tone]. This constraint is not included in the inventory of faithfulness constraints by Morén & Zsiga (2006), nor is it included here.

The constraint, C.G.Coda \rightarrow L also explains the grammaticality of falling tone, but not high or rising tone in cases with underlying high tone. This is shown in tableau (28) below, (from Morén & Zsiga 2006:146 ex. 33).

(28) High tone maps to falling tone in checked syllables with long vowels

	/la:k-H/ 'to tow'	C.G.Coda \rightarrow L	*[TT] σ	ALIGN-Right
a.	HL μμ ∨ l a k ²		*	*
b.	H μμ ∨ l a k ²	*!		

Only candidates that retain the H tone are shown in this tableau. H-tone must surface due to MAX-H outranking C.G.Coda \rightarrow L. In the winning candidate (28a), an L-tone is inserted on the second mora so that C.G.Coda \rightarrow L is also satisfied. The winning candidate violates the constraint, *[TT] σ (*2TONES) due to the contour tone and Align-R since the H tone is not aligned at the right syllable edge. These constraints are subordinated to C.G.Coda \rightarrow L, thus allowing candidate (28a) to be selected optimally. Candidate (28b) is not optimal because the H tone on the second mora incurs a fatal violation of C.G.Coda \rightarrow L, (the same holds for a candidate with rising tone). As a result, candidate (28b) incurs a fatal violation of C.G. Coda \rightarrow L, and candidate (28a) with falling tone is the optimal solution in preserving underlying H tones in checked syllables.

Finally, in order to account for the fact that high, but not falling tone, can occur in checked syllables with short vowels, the constraint REALIZETONE is introduced. This

constraint is violated by a tone that is not associated to a sonorant segment. **REALIZE TONE** is defined in (29) (from Morén & Zsiga 2006:148 ex. 37):

- (29) **REALIZE TONE**: Tones must be associated to a segment that can support vocal fold vibration.

Recall that unchecked syllables with short vowels are represented such that the second mora is associated only to the obstruent coda, as shown in (21a) above. Since the obstruent coda is not a segment that can support vocal fold vibration, **REALIZE TONE** has a potential role to play. For example, consider a similar input to the one shown in (27) above, but with a short vowel instead of a long vowel, as shown in tableau (30) below (from Morén & Zsiga 2006:149 ex. 39). This tableau shows that **REALIZE TONE** and **C.G.Coda → L** must both dominate a constraint that penalizes a tone associated to more than one mora (*[μμ]T).

- (30) Mid tone maps to low tone in unchecked syllables

	/lak/ 'steak'	REALIZE TONE ; C.G.Coda → L		*[μμ]T
a.	$\begin{array}{c} \mu\mu \\ \quad \\ l a k^2 \end{array}$		*!	
b.	$\begin{array}{c} L \\ \\ \mu\mu \\ \quad \\ l a k^2 \end{array}$	*!		
c.	$\begin{array}{c} L \\ \wedge \\ \mu\mu \\ \quad \\ l a k^2 \end{array}$			*

Unlike with a long vowel, when the vowel is short, the optimal candidate (30c) has an L tone that is shared between both moras. The candidate with the L tone right-aligned (30b) fatally violates *REALIZE*TONE because the L tone is linked only to the obstruent coda, which cannot support vocal fold vibration. As before in (27), insertion of an L tone is required to avoid fatal violation of *C.G.Coda* → L, as candidate (30a) attests. A violation of the constraint, *[$\mu\mu$]T is tolerated in the winning candidate (30b).

*REALIZE*TONE also plays an important role in determining that H tone, rather than HL tone, surfaces in unchecked syllables with short vowels. An input with HL tone is mapped to an output with only H tone spanning two moras, as shown in tableau (31) below (from Morén & Zsiga 2006:151 ex. 42).

(31) HL maps to H2 in unchecked syllables with short vowels

	/lak-HL/ ‘to steal’	<i>REALIZE</i> TONE	*[TT] μ	<i>C.G.Coda</i> →L
a.	HL ∨ $\mu\mu$ l a k ²		*!	
b.	HL $\mu\mu$ l a k ²	*!		
c.	H ∧ $\mu\mu$ l a k ²			*

It is not possible to preserve both the H and L tones in the output. The constraint *[TT] μ is fatally violated when a single mora is linked to two tones, as is the case in candidate (31a).⁵⁰ However, if the L tone is only linked to the second mora, as in candidate (31b),

⁵⁰ This constraint of Morén & Zsiga’s is assumed as part of GEN in the current account.

this fatally violates *REALIZE*TONE. Therefore the optimal candidate is the one in which only a single H tone remains, candidate (31c)⁵¹. The H tone is retained, rather than the L tone because *MAX*[H] dominates *MAX*[L] (see Morén & Zsiga 2006:151 ex. 44).

This accounts for the patterns seen in checked syllables. The following sections introduce the constraints that must be added to Morén & Zsiga's system, ultimately arriving at an analysis that accounts for onset- and coda-tone interactions simultaneously. For reference, the final ranking of Morén & Zsiga's OT analysis is shown in Appendix C (Morén & Zsiga 2006:152). Constraint definitions, both those of Morén & Zsiga and the present analysis, are defined in Section 5.2.7.

5.2.5 *Interactions Between Onsets, Codas and Tones*

This section presents an Optimality-theoretic account of the interactions seen between onsets and codas, when they are simultaneously present in Thai. It is argued that constraints modulating coda-tone and onset-tone interactions are not sufficient to account for the fact that only low tone is attested when both the coda and onset are [+CG]. As a result, a markedness constraint is adopted that is suggested by Chen (2007) as a modification to a local conjunction first proposed by Ruangjaroon (2006), that bans such sequences directly.

Ruangjaroon's (2006) generalization of the consonant-tone interactions between onsets and codas in Thai shown in Chapter 2, was altered to include rising tones based on the results of the experiments in Chapter 4. However the basic generalizations in unchecked syllables are assumed to be correct. The summary of consonant-tone

⁵¹ Notably, candidate (31c) also violates *MAX*[L], while (31a, b) do not. Therefore, *REALIZE*TONE must dominate *MAX* [L].

restrictions by syllable type in the native Thai stratum, based on the findings in Chapter 4 is repeated in Table 36 below.

Table 36
Consonant-Tone Restrictions in Thai (Native stratum)

	Onset	Mid Tone	Low Tone	Falling Tone	High Tone	Rising Tone
Unchecked	C _{else}	✓	✓	✓	✓	✓
	T	✓	✓	✓	×	×
	D	✓	✓	✓	×	×
Checked	C _{else} & long V	×	✓	✓	×	×
	C _{else} & short V	×	✓	×	✓	×
	T	×	✓	×	×	×
	D	×	✓	×	×	×

At the heart of this pattern of consonant-tone restrictions, is a tricky conundrum: H tone is attested (in the form of falling tone) following [+CG] onsets, in unchecked syllables as well as in checked syllables that do not have [+CG] onsets. However, in checked syllables that have *both* a [+CG] onset and coda, H tone is unattested. It is not possible to account for this fact using any version of Morén & Zsiga's (2006) C.G.Coda → L constraint, since this constraint allows HL tone in checked syllables. Similarly, neither the constraint used by Lee (2008, 2011), banning [+CG]-high tone sequences, nor the constraint used in the present account (*[+CG]-[H]_{μ2}) can accomplish this on its own. Since exceptions are seen where H tone occurs with both [+CG] codas and onsets, both constraints must be dominated by MAX[H]. If that is the case, how is it that H tone

cannot surface at all when both the coda and the onset are [+CG]? This gang-up effect is not easily accounted for.

The generalization is that the simultaneous presence of a [+CG] coda and a [+CG] onset *together* is worse than the presence of either on its own. Realizing this, Ruangjaroon (2006) employed a local conjunction of these two constraints, ranking it above MAX[H] in order to explain the absence of H tone in this environment. While local conjunction introduces many issues (as argued by Chen 2007 in a reply to Ruangjaroon 2006), the basic generalization appears unavoidable. As a solution to this, Chen (2007) offers a markedness constraint banning the sequence directly: *[[+CG]...H...[+CG]]σ. This constraint is adopted in my analysis as a way to overcome this conundrum outlined above. By ranking *[[+CG]...H...[+CG]]σ above MAX[H], high tone is disallowed in syllables with a [+CG] onset and a [+CG] coda. This is illustrated below in tableau (32).

(32) Only low tone surfaces in checked syllables with [+CG] onsets

/pá:t HH/	*[[+CG]...H...[+CG]]σ	MAX[H]	C.G.Coda → L	*L	Align-L
a. pá:t HH	*!		*		*
b. pà:t ML		*		*	*
c. pa:t MM		*	*!		

5.2.6 Rising and High Tone Restrictions

This section presents an OT-account of onset-tone restrictions in Thai. Previous accounts of onset-tone interaction (Lee 2008, 2011; Ruangjaroon 2006) assumed that only high tone, and not falling or rising tone was banned following [+CG] onset consonants. However, Chapter 2 has shown that rising tone is also banned in the same environment. As discussed in section 5.1, rising and high tone are both phonetically

rising, a fact that is accounted for phonologically by assuming an H tone autosegment that is linked to the second mora only for both rising and high tones. The generalization then is that syllables with a second H-tone mora cannot occur with [+CG] onset consonants. In order to account for this, a constraint is proposed that bans high and rising tone, but not falling tone by referring to an H tone in the second mora. This constraint is formulated in (33) below.

(33) * [+CG] - [H]_{μ2}: * [+CG] – X – H

“Incur one violation per H tone autosegment that is linked to the second mora in a syllable that has a [+CG] onset consonant.”

This constraint is motivated by the fact that tonal information is usually carried late in the syllable, as opposed to early in it (Cutler & Chen 1997; Xu 1999, 2004). As a result, even though the H is not immediately adjacent to the [+CG] segment, the second mora may be the more important one, thus acting as the “licensing” position for tone in the syllable. This is consistent with Morén & Zsiga’s observation that low and high tones have late phonetic targets as well.⁵²

The constraint, * [+CG] - [H]_{μ2} is not violated by CG-falling sequences, but it is violated by CG-high and CG-rising sequences. As such, it captures the pattern of onset-

⁵² An alternative version of this constraint is that falling contours are less marked following [+CG] consonants. Since glottal constriction causes F0 to decrease, the phonology may encode a constraint that is violated by rising contours following these onsets. This option makes the same predictions for Thai, but would make different predictions typologically. This possibility is an area for future research.

tone interaction accurately, mapping H tone inputs to HL tone on the surface⁵³. This is demonstrated in tableau (34) below for a hypothetical input with two H tones.

(34) *_[+CG][-H]_{μ2}, MAX[H] >> *_L, *2TONES, ALIGN-R

/pá: HH/	* _[+CG] [-H] _{μ2}	MAX[H]	* _L	*2TONES	ALIGN-R
a. pá: HH	*!				
b. pá: MH	*!	*			
c. pâ: HL		*	*	*	*
d. pǎ: LH	*!	*			
e. pa: MM		**!			

Assuming Richness of the Base (Prince & Smolensky 1993/2004), it is important to show that non-occurring consonant-tone sequences are mapped to some sequence that does occur. In the case of an input CV: syllable with H tone and a [+CG] onset, like /pá:/, it will surface with HL tone, as long as *_[+CG][-H]_{μ2} dominates *_L, *2TONES, and ALIGN-R, as tableau (34) shows. Candidates (34a), (34b) and (34c) fatally violate *_[+CG][-H]_{μ2} due to the H tone associated to the second mora. A candidate that gratuitously deletes H tones in the input (34d) incurs an extra fatal violation of MAX[H]. The optimal candidate (34b) retains the H tone that is associated to the first mora. A single violation of MAX[H] is unavoidable and additional violations of *_L, *2Tones and ALIGN-R are tolerated because MAX[H] outranks them.

Additionally, an underlying rising tone CV: word with a [+CG] onset will surface as HL, as long as *_[+CG][-H]_{μ2} and either MAX[H] or MAX[L] dominates LINEARITY (TONE). This is demonstrated in tableau (35) below.

⁵³ In Lee (2008, 2011)'s account, H is mapped to HL tone by appealing to OCP constraints that group mid and high together under a feature [-lower] and mid and low together under a feature [-upper]. The current account does not use the OCP to drive this mapping. An advantage of the current account is that it does not need to refer to [lower] and [upper] features, only to H and L autosegments.

(35) *[+CG]-[H]_{μ2}, MAX[H] or MAX[L] >> LINEARITY (TONE), *H, *L

/pă: LH/	*[+CG]-[H] _{μ2}	MAX[H]	MAX[L]	LINEARITY (TONE)	*H	*L
a. pă: LH	*!				*	*
b. pâ: HL				*	*	*
c. pa: MM		*!	*			
d. pá: MH	*!		*		*	
e. pà: ML		*!				*

Candidate (35a) is the faithful candidate, but the sequence of the [+CG] consonant followed by the LH tone violates *[+CG]-[H]_{μ2}. Likewise a candidate (35d) that surfaces with high tone (MH) also violates *[+CG]-[H]_{μ2}. The optimal candidate (35b) satisfies *[+CG]-[H]_{μ2} by altering the linear order of the tones, violating LINEARITY (TONE). Candidates (35c) and (35e), with mid and low tone respectively fatally violate MAX[H].

A second amendment to Morén & Zsiga's (2006) account when considering the right-alignment of H tones. The constraint ALIGN-R was employed by Morén & Zsiga to ensure that H and L tones are right-aligned preferentially, rather than left-aligned, thus explaining the rising phonetic contour in high-tone syllables. Tableau (36), from Morén & Zsiga (2006:139 ex. 18) illustrates this.

(36) Right-alignment of tones (ALIGN-R > ALIGN-L, MAXLINKMORA[T])

	H μμ V /na/ 'aunt'	ALIGN-Right	ALIGN-Left	MAXLINKMORA[T]
a.	H μμ V na	*!		
b.	H μμ V na		*	*

Note that the underlying form has a left-aligned H tone. Candidate (36a), which is the faithful candidate, fatally violates ALIGN-R. The optimal candidate (36b) avoids this violation by shifting the H tone onto the second mora. The same ranking will derive a right-aligned L tone as well.

However, when the onset consonant is [+CG], Morén & Zsiga's account fails to predict the correct outcome. Consider a similar input as the one shown in (36) above, but with a [+CG] onset. Assuming the H tone is preserved via MAX[H], then falling (HL) tone must be the optimal candidate. However, there is no constraint in Morén & Zsiga's system that prefers HL to HM, given an HM input. This situation is illustrated in tableau (37).

(37) Left-aligned H tone can surface with [+CG] onsets

*[+CG]-[H]_{μ2}, MAX[H] >> ALIGN-R, *L, *2TONES, ALIGN-L

/pá: HM/	*[+CG]-[H] _{μ2}	MAX[H]	ALIGN-R	*L	*2TONES	ALIGN-L
☹ a. pá: HM			*			
☺ b. pâ: HL			*	*	*	*
c. pá: MH	*!					*
d. pa: MM		*!				

Without a [+CG] onset, ALIGN-R would select right-aligned H preferentially (MH) over left-aligned H (HM). However, the constraint *[+CG]-[H]_{μ2} is fatally violated when a [+CG] onset is present, as can be seen in candidate (37c). Candidate (37d), where the H tone is deleted, fatally violates MAX[H]. As a result, the competition is between candidates (37a) and (37b), where the first mora retains the H tone and the only difference is whether or not an L tone is inserted on the second mora. However, the

presence of the left-aligned H tone incurs one violation of ALIGN-R in both candidates. As a result, lower ranked constraints, *L, *2Tones, and ALIGN-L would optimally select the faithful candidate. This would make an incorrect prediction however. The required mapping is for candidate (37b) to insert an L tone on the second mora. There is no constraint in Morén & Zsiga's system that would prefer insertion of L over the faithful candidate.

A solution to this problem appears to be available by replacing ALIGN-R with a version that is violated by HM and LM sequences but not HL and LH sequences. One way to accomplish this is via a reference to the right edge of syllables, rather than tones.

- (38) ALIGN(σ , Right, Tone, Right) – Assign one violation for each syllable that does not have a tone aligned at its right edge.

By requiring alignment to the syllable-edge, rather than each tone, this prevents HM sequences such as in candidate (37a) above, while still allowing HL sequences as in (37b) above. This constraint runs afoul however with toneless (mid tone) syllables. ALIGN(σ , Right, Tone, Right) would prefer epenthesis of high or low tones to a toneless mid tone syllable, thus predicting that mid tone should never appear in Thai. This is not quite the right constraint then.


Instead, the constraint LIC-T-Rt is proposed that is violated explicitly by HM and LM sequences and no other sequences. This constraint is defined in (39) below.

- (39) LIC-T-Rt – Assign one violation for a syllable associated with a tone, but whose rightmost mora is not associated to a tone (*HM, LM).

Similar to the *[+CG]-[H]_μ2 constraint, LIC-T-Rt is one that references the rightmost mora. It captures the fact that if there is going to be a single tone, it is relatively more marked to align this tone on the left side of the syllable than on the right side. The fact that tonal targets tend to be realized late in syllables cross-linguistically is the main impetus for tonal alignment in the first place (Yip 2002:83,147; Xu 1999). This constraint is vacuously satisfied by toneless syllables (mid tone) and is satisfied by contour tones, since the second mora is associated with a tone.

Unlike ALIGN-R, LIC-T-Rt is able to distinguish between candidates (37a) and (37b), preferring an HL sequence over HM. Tableau (40) below demonstrates this.

- (40) LIC-T-Rt >> *L, *2Tones, ALIGN-L

/pá: HM/	ALIGN-R	LIC-T-Rt	*L	*2TONES	ALIGN-L
a. pá: HM	*	*!			
 b. pâ: HL	*		*	*	*

In addition, LIC-T-Rt takes care of the basic fact that tones are right-aligned preferentially in Thai, shown in (36) above. As long as one of LIC-T-Rt or ALIGN-R dominates Align-L and MAXLINKMORA[T], the correct mapping will be made.

In this section two novel constraints were introduced that can account for the pattern seen in Thai onset-tone interaction. Together, the constraints, *[[+CG]...H...[+CG]]σ, LIC-T-Rt and *[+CG]-[H]_μ2 can be added in to the system of Morén & Zsiga (2006) in order to account for the full set of consonant-tone interaction data of Thai. The final

ranking is summarized via a skeletal basis with support, generated by OT Workplace (Prince & Tesar 2013) in Appendix E.

5.2.7 *Constraint Definitions*

This section lists definitions for all constraints used in the phonological account of the native stratum of Thai. The majority of the constraints are from Morén & Zsiga (2006). The final two constraints are the novel ones and are noted as such.

- (41) *[H]: One violation per H tone autosegment (Morén & Zsiga 2006:135 ex. 7).

- (42) *[L]: One violation per L tone autosegment (Morén & Zsiga 2006:135 ex. 7).

- (43) MAX[H]: Every H tone autosegment in the input has a correspondent in the output (Morén & Zsiga 2006:136 ex. 8). One violation per input H tone that does not have an output correspondent.

- (44) MAX[L]: Every L tone autosegment in the input has a correspondent in the output (Morén & Zsiga 2006:136 ex. 8). One violation per input L tone that does not have an output correspondent.

- (45) *2TONES: Two tones within the same syllable domain are prohibited (*[TT]σ in Morén & Zsiga 2006:136 ex. 11). One violation per syllable with more than one tone.

- (46) ALIGN-R: A version of generalized alignment (McCarthy & Prince 1993);
 “Align(T, Right, Syllable, Right) – align the tone at the right edge of the syllable”
 (Morén & Zsiga, 2006:138 ex. 15-16). One violation per tone that is not aligned at the right edge of a syllable.
- (47) ALIGN-L: A version of generalized alignment (McCarthy & Prince 1993);
 “Align(T, Left, Syllable, Left) – align the tone at the left edge of the syllable”
 (Morén & Zsiga, 2006:138 ex. 15). One violation per tone that is not aligned at the left edge of a syllable.
- (48) MAXLINKMORA[T]: Do not lose an association between a mora and a tone
 (Morén & Zsiga, 2006:138 ex. 17). One violation per mora-tone association in the input that does not have an output correspondent association.
- (49) * $[\mu\mu]$ TONE: “two moras within the same tonal domain are prohibited (called MONO-SPAN by Bickmore (1996), *MULTIPLE LINK, *SHARE, *SPREAD)”
 (Morén & Zsiga 2006:140 ex. 23). One violation per tone that is linked to more than one mora.
- (50) * $[\text{HH}]\sigma$: Two high tones within the same syllable domain are prohibited
 (OCP[H]) (Morén & Zsiga 2006:141 ex. 25). One violation per pair of H tones within the same syllable.

- (51) *[LL]σ: Two low tones within the same syllable domain are prohibited (OCP[L]) (Morén & Zsiga 2006:141 ex. 26). One violation per pair of L tones within the same syllable.
- (52) C.G.Coda → L: Constricted glottis coda segments must be associated with low tone (Morén & Zsiga 2006:143 ex. 31). One violation per coda that is not associated to an L tone.
- (53) LINEARITY (TONE): Preserve the linear order of *tonal autosegments*. One violation per pair of autosegments whose linear order in the output is not the same as in the input. Note this departs from the more general version used by Morén & Zsiga (2006:147 ex. 35) that applies to all features and segments.
- (54) REALIZE TONE: Tones must be associated to a segment that can support vocal fold vibration (a sonorant) (Morén & Zsiga 2006: 148 ex. 37). One violation per tone that is not associated to a sonorant.
- (55) *[[+CG]...H...[+CG]]σ: One violation per H tone autosegment that is flanked by a [+CG] onset and a [+CG] coda, within the same syllable (Chen 2007).
- (56) * [+CG]-[H]μ2: One violation per H tone autosegment that is linked to the second mora in a syllable that has a [+CG] onset consonant (novel constraint).

- (57) LIC-T-Rt: One violation for a syllable associated with a tone, but whose rightmost mora is not associated to a tone (*HM, LM) (novel constraint).

5.3 *An OT Account of Consonant-Tone Interaction in Loan and Native Strata*

While the previous section detailed an Optimality-theoretic account of the consonant-tone interaction in the native stratum of Thai, this section aims to account for the pattern seen in the loan stratum. With respect to unchecked syllables, the difference between the two strata is that in the loan strata, [+CG]-H tone sequences are grammatical. However, a single sequence, the voiced-rising sequence, was found to be ungrammatical in Experiment 1 in Chapter 4. In addition, the lexical gap status in Chapter 2 suggested that high tone is allowed in checked syllables in English loans as well, but that mid and rising tone are unattested in checked syllables. Falling tone was attested frequently in syllables with [–CG] onsets and long vowels; however the dictionary search yielded three⁵⁴ falling tone examples with [+CG] onsets, all with short vowels. It is assumed that these examples constitute evidence that falling tone is grammatical in checked syllables, even with short vowels.

The analysis here assumes that faithfulness constraints are relativized to each stratum, and that the relative ranking of these faithfulness constraints should account for the difference between the strata (Ito & Mester 1995, 1999, 2001). The generalization in English loans is shown in Table 37. This generalization is based on the results from Chapter 4, where only the voiced-rising sequence was found to be ungrammatical. It also

⁵⁴ On May 9, 2013, only two of these examples remained in the online dictionary: [krûp] “blood group” and [bîk] “big”.

incorporates the lexical gap findings from Chapter 2, treating the “under-represented” and “attested” sequences as grammatical, and only the “unattested” sequences as ungrammatical.

Table 37
Consonant-Tone Restrictions in the English Loan Stratum

	Onset	Mid Tone	Low Tone	Falling Tone	High Tone	Rising Tone
Unchecked	C _{else}	✓	✓	✓	✓	✓
	T	✓	✓	✓	✓	✓
	D	✓	✓	✓	✓	x
Checked	C _{else} & long V	x	✓	✓	✓	x
	C _{else} & short V	x	✓	✓	✓	x
	T	x	✓	✓	✓	x
	D	x	✓	✓	✓	x

5.3.1 Onset-Tone Restrictions

First, in unchecked syllables, the constraint *[+CG]-[H]_{μ2} must be ranked below LINEARITY (TONE)_{LOAN} in order to allow LH sequences to surface faithfully following [+CG] unaspirated stops. This is illustrated in tableau (58), where candidate (58a) fatally violates LINEARITY (TONE)_{LOAN} allowing candidate (58b) to be optimal, despite the violation of * [+CG]-[H]_{μ2}.

(58) Rising tone following [+CG] onsets (Loan Stratum)

/pă:/	LINEARITY (TONE) _{LOAN}	*[+CG]-[H] _{μ2}
a. pâ:	*!	
b. pă:		*

However, this ranking would allow *voiced-rising* sequences to surface if left as is. In order to avoid this, a more specific markedness constraint $*[+voice]\text{-LH}$, violated by a sequence of a voiced stop onset followed by LH tones within a syllable, must outrank $\text{LINEARITY (TONE)}_{\text{LOAN}}$. This is shown in tableau (59).

(59) Voiced-rising sequences are disallowed (Loan Stratum)

	/bă:/	$*[+voice]\text{-LH}$	$\text{LINEARITY (TONE)}_{\text{LOAN}}$	$*[+CG]\text{-[H]}\mu 2$
☞	a. bâ:		*	
	b. bă:	*!		*

The faithful candidate (59b) fatally violates $*[+voice]\text{-LH}$. The winning candidate (59a) satisfies $*[+voice]\text{-LH}$ by switching the linear order of the L and H tones, surfacing with falling tone. This violation of $\text{LINEARITY (TONE)}_{\text{LOAN}}$ is tolerated in order to avoid violating the higher ranked $*[+voice]\text{-LH}$. This ranking derives the onset-tone restrictions seen in loan words and is summarized in (60) below.

(60) Ranking for onset-tone restrictions in the English loan stratum

$*[+voice]\text{-LH} \gg \text{LINEARITY (TONE)}_{\text{LOAN}} \gg *[\text{+CG}]\text{-[H]}\mu 2 \gg \text{LINEARITY (TONE)}_{\text{NATIVE}}$

5.3.2 Checked Syllable Restrictions in Loans

This section outlines an account of the checked syllable restrictions in English loans. First, high and falling tones are attested in CVC loan words with $[\text{+CG}]$ onsets and codas. This means that the markedness constraint, $*[[\text{+CG}]\dots\text{H}\dots[\text{+CG}]]\sigma$ must be dominated by $\text{MAX[H]}_{\text{LOAN}}$ as shown in (61).

(61) H tone is grammatical in checked syllables with [+CG] onsets (Loan Stratum)

/pâ:t/	MAX[H] _{LOAN}	*[[+CG]...H...[+CG]]σ
a. pâ:t		*
b. pà:t	*!	

In the native stratum, candidate (61b) was selected optimally due to the markedness constraint *[[+CG]...H...[+CG]]σ, which is ranked above MAX[H]_{NATIVE}. However, in the loan stratum, MAX[H]_{LOAN} is ranked above *[[+CG]...H...[+CG]]σ, resulting in a fatal violation of MAX[H]_{LOAN} in candidate (61b). As a result, candidate (61a) is optimal, allowing falling and high tone to surface in CVC words with [+CG] onsets in the loan stratum.

While falling and high tone words are attested in CVC words with [+CG] onsets, rising tone is not. In the analysis for the native stratum in the previous section, the constraint *[[+CG]...H...[+CG]]σ was responsible for rising, falling and high tones being ungrammatical in checked syllables with [+CG] onsets. However, the loan stratum pattern suggests that this is not the case. An independent explanation exists for this observation. Rising tone is marked in relation to falling and non-contour tones due to the fact that it requires increased articulatory effort (Zhang 2001). Alternatively, rising tone has also been claimed to be marked preceding glottal segments, a class which codas in Thai belong to (Yip 1982, 2002; Morén & Zsiga 2006:117). Both observations suggest the existence of a markedness constraint that would be violated by rising tone in CVC syllables but not by falling or high tone. The constraint defined in (62) captures this effect.

- (62) *[LH-Obs] σ – One violation is incurred for obstruent segments preceded by LH contours within the same syllable.

The constraint in (62) must dominate LINEARITY (TONE)_{LOAN} in order to prevent rising tone from surfacing in checked syllables, as tableau (63) illustrates. This same ranking argument holds in the native stratum in fact, but the fact that *[[+CG]...H...[+CG]] σ is needed anyway, trumps its effect.

- (63) Rising tone is not allowed in checked syllables (Loan Stratum)

	/p ^h ă:t/	*[LH-Obs] σ	LINEARITY (TONE) _{LOAN}
☞	a. p ^h â:t		*
	b. p ^h ă:t	*!	

The faithful rising-tone candidate (63b) fatally violates *[LH-Obs] σ since the rising tone precedes an obstruent coda. The falling tone candidate (63a) avoids violating *[LH-Obs] σ , by swapping the linear order of the tones, in violation of the lower-ranked constraint, LINEARITY (TONE)_{LOAN}.

The final step is to account for the lack of mid tone in checked syllables with [+CG] onsets. In Morén & Zsiga's account of coda-tone interaction, the constraint C.G.Coda \rightarrow L simultaneously militated against rising, high and mid tone from occurring in checked syllables. However, the pattern seen in the loan stratum presents a challenge here since high tone is attested and mid tone is not. Recall that C.G.Coda \rightarrow L was responsible for mapping any input with H tone to a falling HL contour. The insertion of the L tone on the second mora was motivated to avoid a fatal violation of C.G.Coda \rightarrow L in the native stratum, as shown in (64) (from Morén & Zsiga 2006:146 ex. 33).

(64) Low tone is inserted in checked syllables (Native Stratum)

/p ^h á:t/	C.G.Coda → L	*2TONES	ALIGN-R
☞ a. p ^h â:t		*	*
b. p ^h á:t	*!		


However, in the loan stratum, high tone surfaces faithfully. The only way to account for this is by reversing the ranking needed in the native stratum in (64). C.G.Coda → L must be ranked below ALIGN-R or *2TONES in the loan stratum, contradicting the requirement in (64), as tableau (65) shows

(65) Low tone is not inserted in checked syllables (Loan Stratum)

/p ^h á:t/	*2TONES	ALIGN-R	C.G.Coda → L
a. p ^h â:t	*!	*!	
☞ b. p ^h á:t			*

This ranking contradiction presents an exception to Ito & Mester's hypothesis that loan strata involve relativized faithfulness, and not markedness. A fixed consistent ranking of markedness constraints can only be achieved if a faithfulness constraint that favors (65b) over (65a) is identified. Such a faithfulness constraint, if ranked above C.G.Coda → L in the loan stratum, would be able to duplicate the effects of *2TONES and ALIGN-R. One such candidate is DEP[TONE]. While this would solve the issue in (65) it also would incorrectly allow mid tone to surface (candidate (66b)) in checked syllables, as shown in (66), and so it cannot outrank C.G.Coda → L. Therefore, there is no faithfulness constraint that can replace *2TONES and ALIGN-R in preventing insertion of the L tone. This must be a markedness effect.

(66) Mid tone is ungrammatical in checked syllables (Both Strata)

/p ^h a:t/	C.G.Coda → L	DEP[TONE]
 a. p ^h à:t		*
b. p ^h a:t	*!	


This then implies that in fact, the ranking in the loan stratum requires a different ranking among markedness constraints in relation to the native stratum: C.G.Coda → L must be demoted below one of *2TONES or ALIGN-R in the loan stratum to allow high tone, but not mid tone. It is not possible to ban high tone in the loan stratum, while allowing mid tone in checked syllables without this markedness reversal.⁵⁵

While many cases of stratal differences in phonology involve more permissive loan strata, it is not a fact that a hierarchical structure always exists. Gelbart (2005) notes that even in Japanese there are exceptions, where the Sino-Japanese stratum is less permissive than the native stratum in many ways. However at the same time, the Sino-Japanese stratum is more permissive than even the foreign stratum in that it is the only stratum that allows palatalized consonants. The presence of these exceptions indicates that the hierarchical model of Ito & Mester (1995, 1999, 2001) is merely a tendency, rather than a universal. Onset-tone interaction in Thai adheres to a hierarchical model, as was shown in Section 5.3.1; however, the pattern seen in codas where the high-tone restriction is relaxed, but the mid-tone restriction is upheld can only be explained via re-ranking of markedness constraints.

⁵⁵ Lee's (2008, 2011) constraint *[-SG]/M-Coda would not face this issue since it explicitly bans mid tone preceding obstruents. However, this constraint is avoided here because mid tone is not marked in any way when preceding a [+CG] coda.

One final loose-end concerns the grammaticality of falling tone in checked syllables with short vowels. In the native stratum, Morén & Zsiga (2006) ranked REALIZE-TONE above MAX[H] to prevent falling tone from surfacing in checked syllables with short vowels. In the loan stratum, both MAX[H]_{LOAN} and MAX[L]_{LOAN} must dominate REALIZE-TONE in order to allow falling tones to surface in checked syllables with short vowels, as shown in (67) below.

(67) Falling tone is grammatical in checked syllables with short vowels (Loan Stratum)

/p ^h ât/	MAX[H] _{LOAN}	MAX[L] _{LOAN}	REALIZE-TONE
 a. p ^h ât			*
b. p ^h ât	*!		
c. p ^h ât		*!	

Both the H and L tones must be preserved since MAX[H]_{LOAN} and MAX[L]_{LOAN} dominate REALIZE-TONE. Candidate (67b) fatally violates MAX[H]_{LOAN} since the underlying H tone is deleted; likewise candidate (67c) fatally violates MAX[L]_{LOAN} since the underlying L tone is deleted. Therefore, the candidate that preserves both H and L tones (67a) is selected optimally, even though the L tone is not associated with a vocalic segment.⁵⁶

⁵⁶ This situation presents an issue: If the L tone is not linked to a vocalic segment, why is it pronounced at all. However, if we include REALIZE-TONE in CON, rather than GEN, then it is assumed that some languages will allow REALIZE-TONE to be violated on the surface. Therefore, it is posited that it is still possible to allow phonetic realization of an L tone associated with the coda, resulting in falling tone on the surface. However, it is predicted that this version of falling tone may be phonetically distinct from the usual bimoraic version.

5.4 A Weighted Constraints Model of the Forced-Choice Task

The OT account of consonant-tone interaction outlined in the previous sections explains the pattern of grammaticality seen in Thai at a very coarse-grained level. However, it does not explain the finer-grained patterns of responses seen in the experiments in Chapter 4, shown again in Figure 23 below.

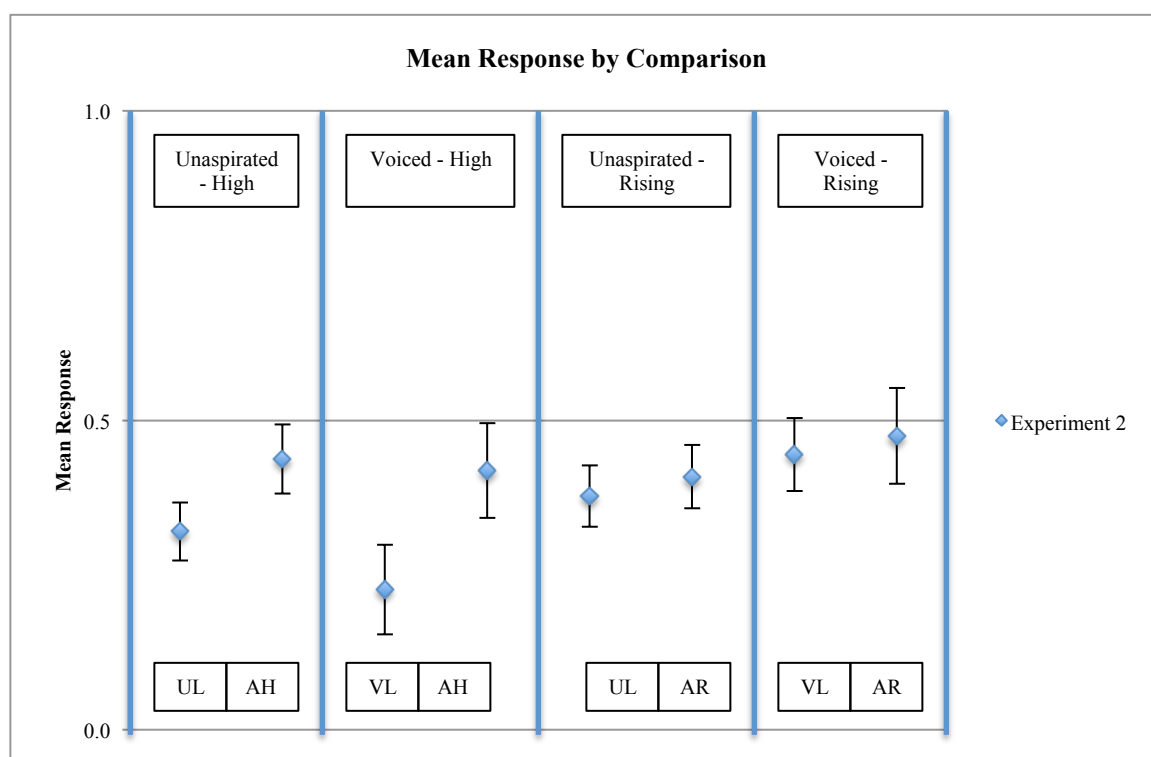


Fig. 23. Experiment 2 Results

Recall that in comparisons varying tone (UH-UL & VH-VL), a more significant trend in the expected direction was seen than in comparisons varying manner (UH-AH & VH-AH). In addition, responses for high-tone comparisons were more significantly biased in the expected direction than responses for rising-tone comparisons were. This section outlines a preliminary account of these finer-grained distinctions by appealing to a model of weighted markedness constraints that explains the behavior in the task. Participants are

presented with two stimuli, non-words of Thai, and are asked to choose which sounds more like Thai. This task involves assessment of relative markedness then. As a result, it is likely that knowledge of the grammar is applied in a non-standard way. The voiced-low and unaspirated-low preferences suggest that markedness constraints that do not feature in the grammar presented above, are exerting an influence. The model here seeks to quantify this influence, in a way that is consistent with the categorical grammar. This approach is similar to Coetzee's (2004) rank-ordering model of EVAL, in that both can explain preferences in judgment tasks between non-words that are both ungrammatical.

The set of markedness constraints used here are logical variations of the constraints proposed by Lee (2008) that account for various patterns of affinity between consonants and tones. Affinities are found between [+SG] and high tone and between both [+voice] and [+CG] and low tone. An attempt to keep each basic force equally represented was made, including the same number of constraints (two) for each affinity.⁵⁷ The complete list of markedness constraints used here, with definitions when relevant, is given in (68). All constraints apply in the domain of the syllable. Only those constraints that are able to distinguish between the experimental stimuli are included in the model. As a result, many of the markedness constraints that feature in the OT account in the previous section do not make an appearance here. Likewise, many of these constraints were not featured in the previous section because they did not play any role in the account (other than needing to be dominated by various other constraints).

⁵⁷ A third constraint encapsulating the [+SG]-high tone affinity at a distance was used since the local version (C12) was never satisfied by any stimulus that contained [+SG], since high and rising tones have right-aligned H. Therefore, this constraint was equivalent to a *[+SG] constraint, in its violation profile, thus not embodying the true force behind the consonant-tone sequence constraint.

(68) Markedness Constraint Inventory

C1: *[+voice]-LH

C2: *[+CG]-[H]_{μ2} (defined in (33) above).

C3: *[H]

C4: *[+CG]...H: H tones must not be preceded at any distance by a [+CG] segment.

C5: *[+voice]...H: H tones must not be preceded at any distance by a [+voice] segment..

C6: *2TONES

C7: *[L]

C8: *[+SG]...L: L tones must not be preceded at any distance by a [+SG] segment.

C9: [+SG]...H: [+SG] segments must be followed by an H tone, at any distance.

C10: [+voice]-L: [+voice] segments must be immediately followed by an L tone.

C11: [+CG]-L: [+CG] segments must be immediately followed by an L tone.

C12: [+SG]-H: [+SG] segments must be immediately followed by an H tone.

C13: *LH (Rising tone is relatively more marked than other contour tones (Zhang 2001)).

The violation profiles for each of these constraints with each of the experimental stimuli is compiled so that for a given comparison in the experiments, that constraint's predicted preference is listed. The violation profiles for the 13 constraints that make at least one decision in the experimental stimulus pairs are given in Table 38. The stimulus on the left for each comparison is arbitrarily defined as the "loser" and the stimulus on the right as the "winner". A "W" denotes that the constraint favors the winner, a "L" denotes that the constraint favors the loser, and "e" denotes that the constraint does not favor either stimulus.

Table 38
Violation profiles by comparison

Comparison	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
UH vs. UL	e	W	W	W	e	e	L	e	e	e	e	e	e
UH vs. AH	e	W	e	W	e	e	e	e	e	e	W	L	e
VH vs. VL	e	W	W	W	W	e	L	e	e	e	e	e	e
VH vs. AH	e	W	e	W	W	e	e	e	e	W	W	L	e
UR vs. UL	e	W	W	W	e	W	e	e	e	e	L	e	W
UR vs. AR	e	W	e	W	e	e	e	L	e	e	e	L	e
VR vs. VL	W	W	W	W	W	W	e	e	e	L	L	e	W
VR vs. AR	W	W	e	W	W	e	e	L	e	e	e	L	e
AH vs. AL	e	e	W	e	e	e	L	L	L	e	e	e	e
UL vs. AL	e	e	e	e	e	e	e	L	L	e	W	L	e
AR vs. AL	e	e	W	e	e	W	e	e	L	e	e	e	W
VL vs. AL	e	e	e	e	e	e	e	L	L	W	W	L	e

To illustrate how the violation profiles will map to a predicted response score, an example is provided. In the comparison between *unaspirated-high* and *unaspirated-low* sequences (UH-UL), the constraint C2 (*[+CG]-[H]_{μ2}) is violated once by the former and not at all by the latter. The prediction is that if this constraint were to have its way, 100% of responses would be for the *unaspirated-low* sequence, which is the “0” value for this comparison. As a result, the constraint has a zero score for the UH-UL comparison ($c_{C2} = 0$). The same constraint would not be violated by either stimulus in the AH-AL comparison however. In this case, the constraint is ambivalent and figures into the predicted mean response for this comparison by contributing a score of 0.5 since it is expected that it will not bias participants either way. At the other end, when a constraint favors the “1” response in a given comparison, it is assigned the score “1”.

The weights of the constraints are determined from the grammar laid out in the previous section. In order to quantify this, whole number weights are assigned, which increase with each successively higher constraint stratum in the final ranking for the grammar.⁵⁸ The lowest stratum is assigned a weight of 1, with constraints from each subsequent higher stratum assigned a weight that is one more than the previous stratum. The stratum itself is determined by applying Biased Constraint Demotion (BCD) (Prince & Tesar 2004). BCD is a model of language learning that assumes markedness constraints are undominated in the initial state and learning involves demoting them below faithfulness constraints. Faithfulness constraints should thus be ranked as low as they possibly can, and BCD accomplishes this. BCD was performed on the skeletal basis for the native Thai grammar as produced in OT Workplace (Prince & Tesar 2013), yielding the following constraint stratum (Stratum 1 is the highest-ranked stratum; stratum 8 is the lowest ranked).

(69) Constraint Strata post-BCD for the Thai Native stratum

Stratum 1 (k = 8): *[+voice]-LH, REALIZE-TONE, OCP-H, OCP-L,

*[[+CG]...H...[+CG]]σ, LIC-T-Rt, *[+CG]-[H]μ2

Stratum 2 (k = 7): MAX[L]

Stratum 3 (k = 6): MAX[H]

Stratum 4 (k = 5): *H, *[CG]...H, C.G.Coda → L, *[+voice]...H

Stratum 5 (k = 4): *2TONES, *L, *[μμ]T, ALIGN-R, *[+SG]...L

Stratum 6 (k = 3): ALIGN-L, [+voice]-L, [+CG]-L

Stratum 7 (k = 2): LINEARITY (TONE)

⁵⁸ This was a strategy suggested to me by Bruce Tesar (p.c.).

Stratum 8 (k = 1): *LH, [+SG]-H

The weighting model multiplies each constraint's score (c_i) by the weighting for that constraint for a given comparison (k_i), then divides by the sum of the weights, yielding a predicted response score, P , that ranges from 0 to 1, as in (70).

(70) Predicted response score for comparison, x

$$P_x = \frac{\sum_{i=C1}^{i=C13} k_i * c_i}{\sum_{i=C1}^{i=C13} k_i}$$

Predicted response scores for each comparison are displayed along with the actual mean responses in Figure 24 below.

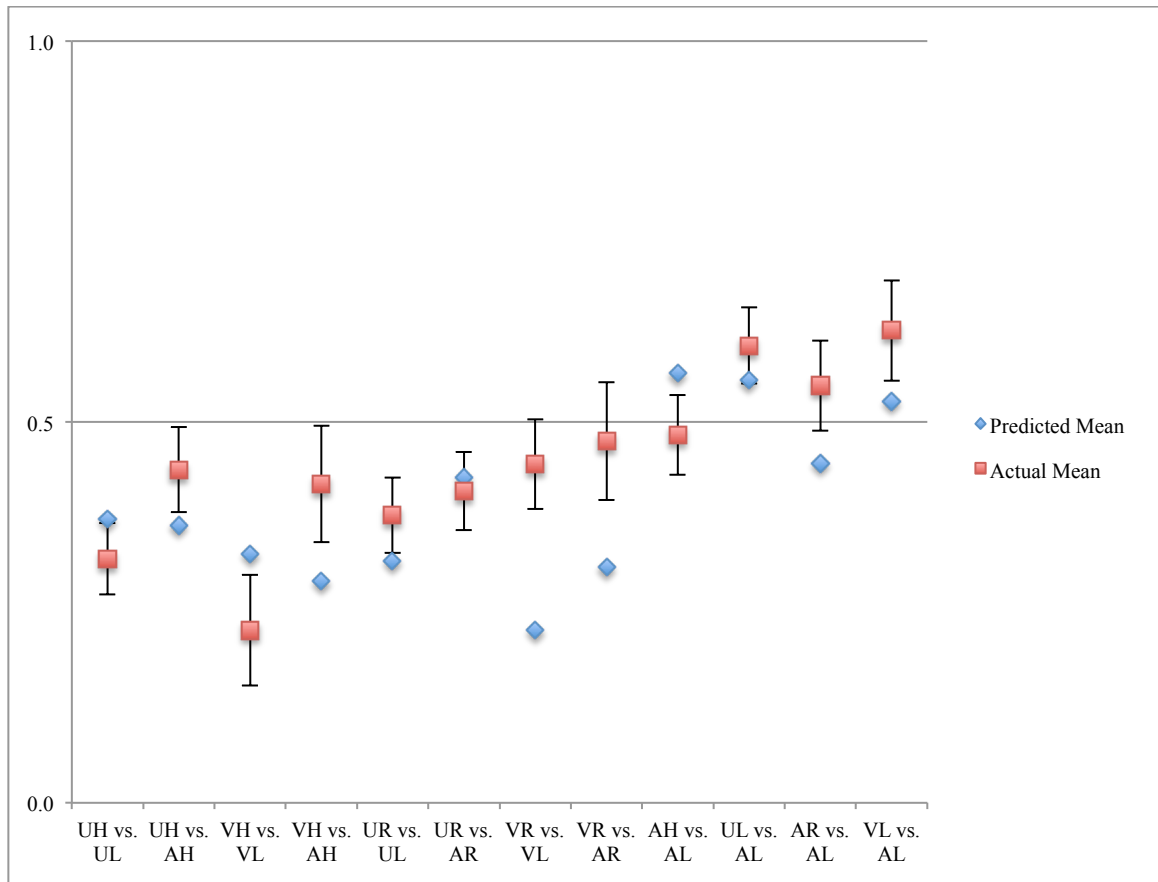


Fig. 24. Predicted response scores by comparison

This prediction is close to the actual response means, but doesn't quite reflect certain details. For example the comparisons varying manner tend to approach random choice to a much greater extent than the model predicts. One relevant hypothesis made in the previous chapter was that participants were more likely to misperceive high and rising tone in comparisons varying manner, and so this difference is best not handled by the grammar if this is the case. Since there is no benchmark low tone in these comparisons, it might be the case that many of the high and rising tones are misperceived. However, in comparisons varying tone, this is considerably less likely since the low tone alternative offers participants a benchmark for comparison. This can be encoded into the model by setting a scaling factor that approximates the effects of misperception in comparisons

varying manner. The transformed predicted means are calculated as follows, with scaling factor, h .

$$(71) \quad \text{Transformed Predicted Mean: } P_t = 0.5 - h(0.5 - P_x)$$

The scaling factor, h was set to $1/3$ for comparisons varying manner, but left at 1 for comparisons varying tone. The results of the transformed predicted mean are plotted with the actual mean responses in Figure 25 below.

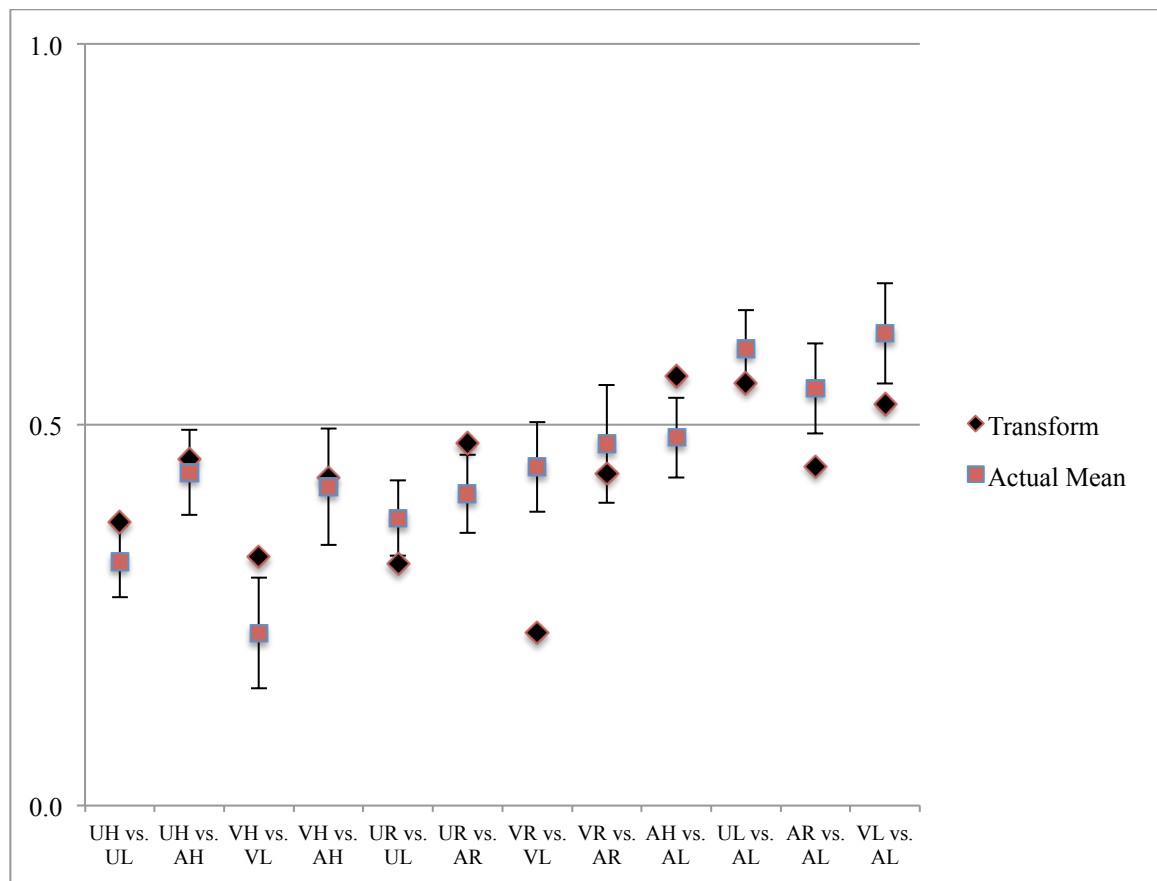


Fig. 25. Transformed predicted response scores by comparison with scaling factor ($h=1/3$) included

The transformed predicted response scores offer a better fit to the actual means. The *voiced-low* and *unaspirated-low* preferences are seen in the model, however the model also predicts that the aspirated-high sequence should be similarly preferred while this is not the case. One observation that may explain some of the discrepancies in Figure 25 is that comparisons between H and L tone tend to be shifted towards L tone in the actual means. This can be seen in the UH-UL, VH-VL and AH-AL comparisons (although not in the UH-UL comparison curiously). One possibility is that the constraint *L should not be included. Cross-linguistic evidence supports the claim that L tone is generally less marked than H tone (Yip 2002:41). One way to encode this is to posit that while the constraint, *[H] exists, *[L] does not. Removing *[L] from the inventory of constraints⁵⁹ would shift the predicted means for the three comparisons involving H versus L tone, UH-UL, VH-VL and AH-AL closer to the actual means, as illustrated in Figure 26.

⁵⁹ Removing *L from the constraint inventory does not affect the constraint ranking for Thai, since *L does not have to crucially dominate any other constraints.

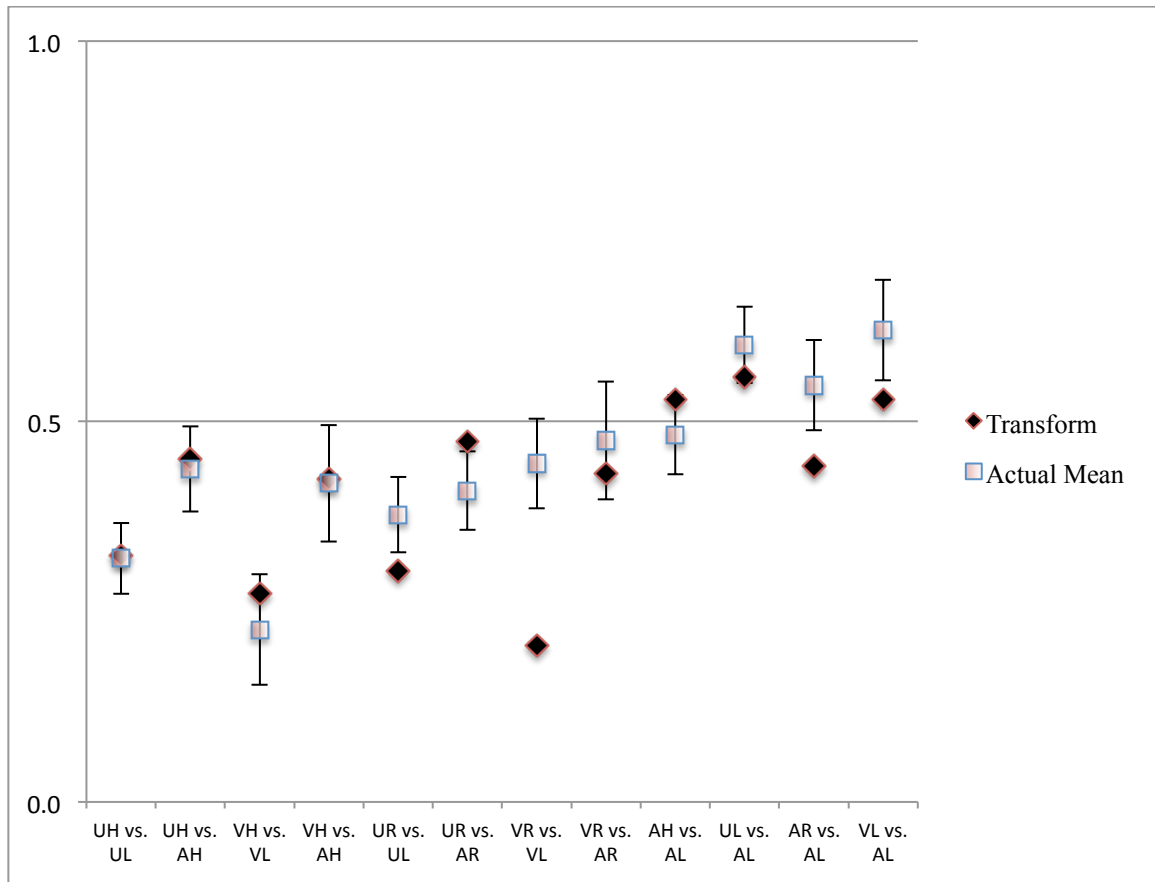


Fig. 26. Transformed predicted response scores by comparison (without *L)

The model proposed here does reasonably well at accounting for finer-grained differences seen in response means across participants. This relative success indicates that the performance on the task can be related to the grammar in a quantitative manner. It also accounts for the fact that low-ranked markedness constraints, otherwise not active in learning Thai can exert an effect in grammaticality judgments both between grammatical forms and even in comparisons involving one grammatical and one ungrammatical form. Since faithfulness constraints are not applicable in this task, the distinction between grammatical and ungrammatical is not a clear one. Instead, this weighted markedness model is proposed to explain performance in a forced-choice task.

5.5 Conclusion

This chapter has outlined an Optimality-theoretic phonological analysis of consonant-tone restrictions in Thai. The account builds on Morén & Zsiga's (2006) account, adding three crucial markedness constraints. First, it is argued that the pattern where only low tone is attested in checked syllables with [+CG] onsets cannot be accounted for by restrictions on onset-tone and coda-tone sequences alone. A constraint that refers to both the coda and onset is required to prevent high tone from surfacing in these syllables. Additionally, two markedness constraints are posited to account for the pattern where rising and high tone, but not falling tone are attested in unchecked syllables following [+CG] onsets. This observation amounts to a paradox for an account that requires locality, since falling but not rising or high tone, involves an H tone adjacent to the [+CG] segment. It is argued that this can be captured by privileging the second mora, following proposals that claim late tone targets may offer articulatory advantages (Xu 1999, 2004). A constraint banning a tonal rise following [+CG] segments bans high and rising tone, but not falling tone in unchecked syllables with [+CG] onsets. Similarly a second constraint, LIC-T-Rt can explain patterns of alignment that ALIGN-R cannot. Both constraints involve reference to the second mora as a privileged position.

The second contribution of this chapter was to offer a separate account of consonant-tone interaction in the native and loan strata of Thai. The account seeks to apply Ito & Mester's (1995, 1999, 2001) hypothesis that higher permissiveness in loan strata is captured by relativized faithfulness constraints that apply to loan items but not to native items. This approach was successful in its ability to explain the lack of the *unaspirated-high*, *voiced-high*, and *unaspirated-rising* restrictions in loans, while accounting for the

presence of the *voiced-rising* restriction. However, the fact that high tone is grammatical in checked syllables but mid tone is not cannot be accounted for via relativized faithfulness. Instead, markedness constraints must be re-ranked in the loan stratum to capture this fact.

Finally, while the OT-account explained the main findings of the experiments in Chapter 4, it does not address finer-grained findings from the experiment. A model is offered that seeks to explain how people may apply information from their grammars in forced-choice tasks, such as the one outlined in Chapter 4. Since the task involves comparisons of candidates, it differs from the usual application of grammar in mapping inputs to outputs. Specifically, faithfulness constraints play no role in the forced-choice comparison task. It was shown that a weighted-constraint model that uses weights based on the relative rankings between markedness constraints from the grammar can account fairly well for the finer-grained response differences.

Chapter 6 – Conclusion

This dissertation provided evidence that consonant-tone interaction in Thai is non-local, at the level of the mora. On the other hand, existing theories of consonant-tone interaction have assumed that a tonal autosegment is adjacent to the consonant with which it interacts (Bradshaw 1998; Lee 2008; Tang 2008). Previous analyses of onset-tone interaction in Thai have focused on a restriction involving high tone; however this dissertation established that a similar restriction exists involving rising tone. Chapter 2 presented evidence from a quantitative study of lexical gaps in Thai; Chapter 4 presented evidence from a judgment experiment that confirmed that both rising and high tone are ungrammatical following [+CG] onset consonants, within open syllables.

It is argued in Chapter 5 that a phonological restriction on onset-tone sequences in Thai references the second, rather than the first, mora. Both high and rising tone share the property of having a late high-tone target, resulting in phonetically rising pitch. On the other hand, falling tone, which has an early high-tone target, is grammatical with [+CG] onset consonants. To solve this dilemma, an Optimality-theoretic constraint, *[+CG]-[H]_{μ2}, is posited that is violated by syllables with [+CG] onsets and whose second mora is linked to an H tone. This constraint essentially treats the second mora as if it were the “head mora” of the syllable, a position that is grounded by the fact that late tonal targets tend to be preferred cross-linguistically. As a result, while the majority of languages with consonant-tone interaction may involve local relations as outlined in theories like Lee’s (2008) for example, Thai appears to constitute an exception. Consonant-tone interaction,

then, is like other phonological processes that involve sequence restrictions, such as vowel harmony and consonant harmony, in that it also can involve non-local relations.

In order to support this phonological analysis, Chapter 3 consisted of an acoustic study of unaspirated and voiced obstruents in Thai, finding that they were articulated with laryngeal constriction. Lowered F0 and spectral tilt seen immediately following voiced and unaspirated obstruent onsets confirmed this. This finding suggests that these sounds form a natural class under the feature value, [+constricted glottis], rather than [–spread glottis] as previous analyses of Thai assumed (Ruangjaroon 2006; Lee 2008). As Lee himself notes, Thai would be the only language in his cross-linguistic survey in which [–spread glottis] is active in consonant-tone interaction. Therefore, the acoustic study confirms that Thai is not exceptional and that it belongs among the more customary group of languages that involve restrictions between [+CG] and high tone.

In addition, the acoustic study highlighted an interesting mismatch between the phonetics and phonology concerning laryngeal constriction in Thai. While the laryngealized obstruents involved lowered F0 and spectral tilt, [ʔ] was associated with raised F0 and spectral tilt. This phonetic difference indicated that there is a difference in the physical mechanism of the laryngeal constriction: Creaky phonation is typically associated with lowered F0 and spectral tilt, whereas harsh or tense phonation is typically associated with raised F0 and spectral tilt, for example. It is proposed that a similar difference in laryngeal constriction exists in consonants, and that in Thai this phonetic difference manifests itself. However, no parallel distinction is seen in the phonology. With respect to consonant-tone interaction, both [ʔ] and laryngealized obstruents are unattested preceding high tone. This mismatch between the phonetics and phonology acts

as a reminder that while phonetic detail can inform phonological processes, it is not a necessary condition; phonology often involves abstractions over finer phonetic details.

While the acoustic experiment established a possible phonetic basis for a phonological process of onset-tone interaction, Chapter 4 presented a judgment experiment that confirmed the psychological reality of the onset-tone restrictions. Thai speakers judged nonce stimuli with sequences of [+CG] onsets followed by rising or high tone as worse than nonce stimuli containing attested onset-tone sequences, under a native interpretation of the stimuli. A second experiment was identical, but prompted the participants to treat the stimuli as if they were English loans. In this case, only one of four onset-tone lexical gaps was judged to be ungrammatical (voiced stop – rising tone sequences). This finding is consistent with Ito & Mester's (1995) hypothesis that loan strata tend to be more permissive, containing a subset of phonological restrictions found in native strata. Stratification of the lexicon has been documented widely in cases like Japanese, German, and Jamaican English; the findings in Chapter 4 indicate that Thai can be added to this list.

Finally, the experiments in Chapter 4 indicated that Thai speakers had preferences in control comparisons that contained two presumably grammatical stimuli. They preferred low-tone stimuli with [+CG] onsets to low-tone stimuli with aspirated onsets, both of which are attested in Thai. This preference accords with theories of consonant-tone interaction, which have established that a [+CG] consonant-low tone sequence is less marked than a [+CG] consonant-high tone sequence. These preferences could not have been learned from the Thai language and so they constitute evidence that constraints are present in the grammar and that humans make use of these, even when they are not

crucial in learning a particular language. This finding is consistent with results seen in other languages, including English (Coetzee 2008, 2009) and Hebrew (Berent & Shimron, 1997), where distinctions are made in judgment experiments among grammatical forms, in the direction predicted by markedness theories. In Chapter 5, a task-specific model of weighted markedness constraints is outlined. This model illustrates how people might apply an Optimality-theoretic categorical grammar such that preferences emerge between two grammatical forms. These preferences are based on the relative ranking of markedness constraints in the actual grammar in a task where faithfulness constraints clearly play no role.

Appendix A

Exceptional Thai Words⁶⁰

Category	Word	Meaning
tV:	pá:w	[n] [the sound of a cat's howl] (not a word – AR)
	pín	[v] to have an ingenious idea pop into one's head (onomatopoeia - AR)
	tiá:m	[n] overnight lodging (AR – Chinese loan)
	teá:w	[euphonious suffix] (Northern dialect – AR)
	teíá:m	[adj] [is] humble, modest, moderate (not high tone – mid tone – AR; bound morpheme – occurs in the word “humble body” compound word)
	teíá:w	[adj] [is] noisy; rambunctious (onomatopoeia – AR)
	kón	[v] to drink (alcohol) (Chinese loan – AR)
	kúj	[n] a person without manners; a base or immoral person (Chinese loan – AR)
	kiá:w	[n] dumpling; wonton (Chinese loan – AR)
	ʔǎ:j	[int] an exclamation of surprise (not a word – AR)
	ʔiá:m	[n] (baby's) bib (Chinese loan – AR)
	pó:	[adj] naked; sexy; pornographic; stimulating; arousing; risqué; indecent; having an aphrodisiac quality (slang – AR)
	tú:	[v] to bother; harass; pester; perturb (polite slang – AR)
tV̌:	pě:w	[adj] [is] innocent; artless; unaffected; unsophisticated
	pǎ:ŋ	[prop.n] [Thai nickname] Bong
	tě:w	[n] an effeminate gay man
	tǎ:j	[prop.n] [Thai male nickname] Toi
	teǎ:ŋ	[adj] [is] lonely; lonesome
	teǎ:j	[adv] very; pleasantly
	krǎ:n	[adj] [is] bare; barren, bald; denuded; thin; naked
	ʔǎ:ŋ	[n] a Chinese prince, king, or monarch
	ʔǎ:j	[adj] intense; bright
	pǐw	[v] to lose; miss out; fail through
	tǎŋ	[v] to secure a mooring line
	teĩm	[prop.n] [a common Thai female nickname]
	teĩw	[adj] minute; small; tiny; little; microscopic; miniscule
	teũm	[prop.n] [a common Thai female nickname]
	kǎw	[adj] [is] smart; cool; great; fine; excellent
	kěŋ	[n] small vestibule; passenger compartment of a boat or car; sedan
	kũn	[n] gizzard
	ʔǎn	[adj] [is] plump; fat; stout
	pĩ:	[adv] totally; completely; fully
	prũ:	[adv] [of moving] swiftly; quickly

⁶⁰ Where more than one meaning exists, the first definition listed in the dictionary is given.

	tũ:	[adv] (of dark) utterly; completely; (of black) pitch
	teǎ:	[adj] having a servile attitude towards (something)
	teǒ:	[n] chimp; ape; monkey
	teǔ:	[v] to poke one's nose into other affair
	teĩ:	[adv] extremely; urgently; intensely
	teũ:	[adj] very short
	kǎ:	[adj] [is] bold; daring; audacious; forward
	ʔǎ:	[part] [a word used at the end of a statement to indicate a question, usually when the response is presumed]
	ʔǒ:	[v, t, i] to console; to soothe; to comfort; to humour; to pamper; to indulge
dǎ:	bǒ:	[adj] [is] pitted; dented-in; sunken; dimpled
	bũm	[adj] [is] dimpled; indented; pock-marked
	dǎ:	[euphonious suffix]
	dǎ:	[adj] [is] clumsy; spastic; dense
	diǎ:w	[adv] soon; shortly; momentarily
Cǎ:T	mó:k	[n] [the action of] oral intercourse
	ró:k	[part] [word often used with statements of contradiction or negation] surely (not), of course (not)
	jé:p	[v] [boxing] to jab
	te ^h á:k	[adj] later than someone or something
	te ^h é:k	cigarette lighter
tǎ:T	pé:p	[n] [clothing] a snap; a catch
	pí:p	[n] bucket; pail; can
	piá:p	[adj, adv] perfectly; absolutely; irrevocably
	piá:k	[adj] little; (of a person) small; tiny
	plé:p	[adv] as a short, stabbing sensation
	prí:t	[v] to spurt out
	tó:k	[adv] leisurely
	teé:t	[adj] [is] intense; excessive; extreme; strong; bright
	teó:k	[adv] copiously; abundantly
	teĩ:t	[adj] tiny; minute; slight; trivial; little; insignificant
	teíá:p	[adv] [cold temperature related to food, water, parts of human body and objects] very, intensely
	teíá:k	[part] [sound made by a monkey]
	ká:t	[n] kerosene; paraffin; white gasoline
	ké:k	[euphonious word]
	kó:k	[n] faucet tap; spout
	krá:t	[euphonious suffix]
	kruá:k	something without substance or essence; junk
	ʔé:t	[prop.n] Aed [a Thai nickname]
	ʔó:k	[v] to weld
dǎ:T	buá:k	[adj] foolish; stupid; idiotic; silly; dim-witted
CǎT	p ^h lǎk	[adv] generously; copiously; freely; in great quantity

	p ^h lê?	[adj] [is] oblique
	t ^h ê?	[v] [as an object] to lean to one side
	lâ?	[v] to forsake; abandon; or leave
	lê?	[n] artifice; trick; stratagem
	rê?	[v] to hawk or peddle
	nâ?	[part] [word added to the end of a sentence to soften it, emphasize, or make it polite, a milder version of uə]
	nî?	[prn] this
	niâ?	[part] [a particle usually used in the interrogative to indicate emphasis]
	k ^h â?	[part] [word added by a female speaker to the end of every question to convey politeness]
CŨT	rř?	[conj, formal] or
tŨT	pê?	[n] backpack; knapsack
	têk	[alliterative suffix]
	teâ?	[part] [spoken to a person of lower status, or to an intimate acquaintance] yes
	?ê?	[n] leader; head honcho
tŨT	páp	[adv] at once; immediately; suddenly
	pé?	[adv] precisely; accurately; exactly
	pék	[n] thumbtack
	pó?	[n] lampshade
	pít	[euphonious word]
	púp	[adv] suddenly; quickly; promptly; instantly; immediately; rapidly; unexpectedly; abruptly; hastily
	púk	[adj] pudgy, fat and cute
	priá?	[adj, adv] [of speaking] fluent; exact; precise; fluently; exactly; precisely
	tú?	[adv] chubby; puffy; plump; obese; fat
	teá?	[part] [word added to the end of a statement or question when speaking to a person of lower status]
	teúp	[n] electric light socket (alternate pronunciation for teúp)
	kák	[n] vest; waistcoat
	kék	[adj] [is] pretentious; stuck-up; haughty; posturing
	kók	[n] clique; gang; group; faction
	kíp	[n] hairpin; hair clip
	kúk	[pfx] [euphonious prefix]
	?íp	[v] [vulgar slang] to fornicate
	?úp	[v] to have sex (with)
tŨT	?ě?	[prop.n] [Thai nickname] Eh
dŨT	bê?	[v] twist; distort; contort
dŨT	bík	[prop.n] [a common Thai nickname]
	búk	[v] book (reserve a seat, ticket)

		diá?		[adj] [of an object, i.e. a ruler] very straight
--	--	------	--	--

Appendix B

A ruby script for processing the Orchid corpus in Thai script.

```
# 3/12/12: Complete; this corpus does not produce any impossible Thai syllables;
# it is accurate for monosyllabic words, but may involve misparsing of onset consonant
# clusters, where C1 may be parsed as a coda of a previous syllable (this is inherently
# ambiguous in Thai orthography). As such, the script is not reliable for words of two
# syllables or more.
```

```
$KCODE='u' # This allows ruby v. 1.8 to handle unicode.
require 'jcode' # Changes base ruby methods to be unicode-sensitive.
```

```
# An object of this class represents a Thai syllable, expressed in up to
# six constituents:
# * vowel_prefix: 0-1 vocalic characters preceding the onset
# * onset: 1-2 consonant characters representing the onset
# * vowel_diacritic: 0-1 vocalic characters following the onset
# * tone: 0-1 characters representing tone
# * vowel: 0-2 vocalic characters representing the vowel
# * coda: 0-2 consonant characters representing the coda
#
# This class also contains some class methods defining character classes,
# and for parsing a Thai script string into an array of syllables.
class Thai_syllable
```

```
  # Each syllable constituent is represented as a string of Thai characters,
  # initialized as an empty string.
```

```
  def initialize
    @v_prefix = ""
    @onset = ""
    @v_diacritic = ""
    @tone = ""
    @vowel = ""
    @coda = ""
    @jonset = ""
    @jvowel = ""
    @jlength = ""
    @jtone = ""
    @jcoda = ""
    @ipa_onset = ""
    @ipa_vowel = ""
    @ipa_tone = ""
    @ipa_length = ""
    @ipa_coda = ""
  end
```

```

# Allow access to the parts of a syllable
def v_prefix
  @v_prefix
end
def onset
  @onset
end
def v_diacritic
  @v_diacritic
end
def tone
  @tone
end
def vowel
  @vowel
end
def coda
  @coda
end
def jonset
  @jonset
end
def jvowel
  @jvowel
end
def jlength
  @jlength
end
def jtone
  @jtone
end
def jcoda
  @jcoda
end

# The following constants define character classes used in regex matching in the class
# methods below
P = /[๗๑๓]/
# Vowel prefixes
NP = /^[๗๑๓]/
# The negation of the vowel prefixes
C = /[กขฟปบมวฝฟดททฐธคฏคฺฉษสชลฬรณญหจขฃฌฅงอหฮญ]/ # Consonants
ONS = /[ฝฬหฮญ]/
# Consonants that only occur in onset
S = /[มวฬรณฃฌญ]/

```



```

def add_vowel(tchar)
  @vowel += tchar
end

def add_coda(tchar)
  @coda += tchar
end

# Add _tchar_ as an onset to the JPA syllable
def add_jonset(tchar)
  @jonset += tchar.to_s
end

def add_jvowel(tchar)
  raise "Cannot have multiple jpa vowels" unless @jvowel.length == 0
  @jvowel += tchar.to_s
end

def add_jlength(tchar)
  raise "Cannot have multiple jpa vowel lengths" unless @jlength.length == 0
  @jlength += tchar.to_s
end

def add_jtone(tchar)
  raise "Cannot have multiple jpa tones" unless @jtone.length == 0
  @jtone += tchar.to_s
end

def add_jcoda(tchar)
  @jcoda += tchar.to_s
end

# Replace the jpa onset with the string _tchar_
def alter_jonset(tchar)
  @jonset = tchar.to_s
end

def alter_ipa_onset(tchar)
  @ipa_onset = tchar.to_s
end

# Add _tchar_ as an onset to the IPA syllable
def add_ipa_onset(tchar)
  @ipa_onset += tchar.to_s
end

```



```
def add_ipa_vowel(tchar)
  @ipa_vowel += tchar.to_s
end
```

```
def add_ipa_length(tchar)
  @ipa_length += tchar.to_s
end
```

```
def add_ipa_tone(tchar)
  @ipa_tone += tchar.to_s
end
```

```
def add_ipa_coda(tchar)
  @ipa_coda += tchar.to_s
end
```

This method attempts to determine, on the basis of the existing vowel,
if the syllable must be open (not have a coda). This is used in parsing
to help determine if a consonant character is possibly a coda.
Returns true if the syllable must be open; false otherwise.

```
def must_be_open?
  return true if @vowel == "ɘ"
  return true if @vowel == "ɤ"
  return true if @vowel == "ə"
  return true if (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ə")
  return true if (@v_diacritic == "") && (@vowel == "ə")
  return true if (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ɘ")
  return true if (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ə")
  return true if (@v_diacritic == "") && (@vowel == "ɤ")
  return true if (@v_diacritic == "") && (@vowel == "ɥ")
  return true if @vowel == "ɿ"
  return false
end
```

This method attempts to determine, on the basis of the existing vowel,
if the syllable must be closed (have a coda). This is used in parsing
to help determine if a consonant character is possibly a coda.
Returns true if the syllable must be closed; false otherwise.

```
def must_be_closed?
  return true if (@v_diacritic == "") && (@vowel == "")
  return true if (@v_diacritic == "") && (@vowel == "ə")
  return true if (@v_prefix == "l") && (@v_diacritic == "")
```

```

    return true if (@v_prefix == "i") && (@v_diacritic == "")
    return true if (@v_diacritic == "") && (@vowel == "")
    return true if (@v_diacritic == "") && (@vowel == "ɔ")
    return false
end

# Returns "true" if the current syllable was formed via a-epenthesis to break up an onset
# cluster; this is true any time there are no vowel or coda characters in a syllable
def epsyll?
    return true if (@v_prefix == "") && (@onset != "") && (@vowel == "")
    && (@v_diacritic == "") && (@tone == "") && (@coda == "")
    return false
end

# This method attempts to determine, on the basis of the context,
# if the current character must be an onset. This is used in parsing;
# it returns true if the character must be an onset; false otherwise.
def Thai_syllable.must_be_onset?(arr,a)
    _ = arr[a]
# General onset contexts:
    # Consonants that cannot appear in coda (or vowel) position must be onsets
    return true if /#{ONS}/ =~ arr[a].to_s
    # Any consonant with a vowel diacritic or tone following it is an onset
    return true if /#{C}(#{D}|#{T})/ =~ arr[a..a+1].to_s
    # Any consonant with an even number of following consonants (forming a
    # syllable with unwritten [o] vowel), the last of which must be an onset due to a
    # following vowel character, must be an onset.
    # This doesn't hold if one of the coda positions is filled by a consonant that can't
    # be a coda.
    # This doesn't hold if there is an obstruent-sonorant-consonant sequence since this
    # can form a complex onset; these exceptional clauses are applied throughout
    return true if
        (/\A#{UC}((#{UC}#{O}#{T})|(#{US}#{C}#{T}))* (#{D}|#{T}|#{U
        V}|ᵿ(#{UC}|#{P}|s|V))/ =~ arr[a..arr.length-1].to_s) &&
        (not(/\A#{UC}((#{UC}#{O}#{T})|(#{US}#{C}#{T}))* #{ONS}/ =~
        arr[a..arr.length-1].to_s)) &&
        (not(/\A#{UC}(#{UC}#{T})* #{O}#{T}? #{US}#{UC}/ =~
        arr[a..arr.length-1].to_s))

    return true if
        (/\A#{UC}((#{UC}#{O}#{T})|(#{US}#{UC}#{T}))* (#{C}|#{V}|ᵿ(
        #{P}|s|V))/ =~ arr[a..arr.length-1].to_s) &&
        (not(/\A#{UC}((#{UC}#{O}#{T})|(#{US}#{C}#{T}))* #{ONS}/ =~
        arr[a..arr.length-1].to_s)) &&
        (not(/\A#{UC}(#{UC}#{T})* #{O}#{T}? #{US}#{UC}/ =~
        arr[a..arr.length-1].to_s))

```

The same is true for *u* if it's not in a vowel context

```

return true if
  (/\A(#{UC}#{O}#{T}?)|(#{US}#{C}#{T}?)*)#{D}#{T}#{UV}|ṽ(#{UC}#{P}|s|s|v)/ =~ arr[a..arr.length-1].to_s) && (not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) &&
  (not(/\A(#{UC}#{O}#{T}?)|(#{US}#{C}#{T}?)*)#{ONS}/ =~ arr[a..arr.length-1].to_s)) &&
  (not(/\A(#{UC}#{T}?)*#{O}#{T}#{US}#{UC}/ =~ arr[a..arr.length-1].to_s))
return true if
  (/\A#{T}#{UC}((#{UC}#{O}#{T}?)|(#{US}#{UC}#{T}?)*)#{C}#{V}|ṽ(#{P}|s|s|v)/ =~ arr[a..arr.length-1].to_s) && (not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) && (not(ṽ#{ONS}/ =~ arr[a..a+1].to_s)) &&
  (not(/\A(#{UC}#{O}#{T}?)|(#{US}#{C}#{T}?)*)#{ONS}/ =~ arr[a..arr.length-1].to_s)) &&
  (not(/\A(#{UC}#{T}?)*#{O}#{T}#{US}#{UC}/ =~ arr[a..arr.length-1].to_s))

```

Any consonant (even vowel-ambiguous ones) that precedes a consonant-syllable-boundary sequence must be an onset if it is also preceded by an unambiguous vowel, unless it is *ɹ*

```

return true if
  (/#{UV}#{C}/ =~ arr[[0,a-1].max..a].to_s) &&
  (/\A#ṽ#{C}#{C}#{V}|ṽ(#{P}|s|s|v)/ =~ arr[a..a+3].to_s) && (not(ṽ/ =~ arr[a].to_s)) && (not(/#{UC}(#{ONS}|ṽ)/ =~ arr[a..a+1].to_s))

```

Line-initial consonants are onsets (with an optional *v* prefix preceding it)

```

return true if (a == 1) && (/#{P}#{C}/ =~ arr[0..1].to_s)
return true if (a == 0) && (/#{C}/ =~ arr[0].to_s)

```

Any consonant that follows a *v* prefix or white-space is an onset

```

return true if (/#{P}|s#{C}/ =~ arr[[0,a-1].max..a].to_s)

```

A consonant with an unambiguous vowel following it is an onset; this is not true for certain characters that can themselves be vowels preceding another vowel; these exceptions are excluded

```

return true if
  (/#{C}#{UV}/ =~ arr[a..a+1].to_s) && not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) || (not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) ||
  (not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) ||
  (not(/#{C}#{C}#{T}?ṽZ/ =~ arr[[0,a-4].max..a].to_s))) &&
  (not(ṽ(ṽ|ṽ|ṽ)/ =~ arr[a..a+1].to_s))

```

A consonant with any vowel character following it is an onset if that vowel precedes a character that must be an onset; the same exceptions as above plus three additional ones apply; not true of *u* as a vowel though

```

return true if
  (/\A#ṽ#{C}#{V}(#{C}|#{PC}|#{DC})(#{D}#{T}#{UV}|ṽ(#{UC}#{P}|s|s|v)/ =~ arr[a..a+7].to_s) && ((not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) || (not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) ||
  (not(ṽ#{T}?ṽZ/ =~ arr[[0,a-2].max..a].to_s)) ||

```

```

(not(/i#{C}??#{C}#{T}?oZ/ =~ arr[[0,a-4].max..a].to_s))) &&
(not(/(o|u|ɔ)z/ =~ arr[a..a+1].to_s)) && (not(/v/ =~ arr[a..a+1].to_s)) &&
(not(/#C}v/ =~ arr[a..a+1].to_s)) && (not(/ɜɜ/ =~ arr[a..a+1].to_s)) &&
(not(/(o|u|ɔ)z/ =~ arr[a..a+1].to_s))

# Certain vowels require open syllables; any consonant following them is an onset
return true if /z#{C}/ =~ arr[[0,a-1].max..a].to_s
return true if /#T}??#{C}\Z/ =~ arr[[0,a-3].max..a].to_s
return true if /#C}??#{C}#{T}?(#{UC}|u|ɜ)Z/ =~ arr[[0,a-4].max..a].to_s

# Any character following ɔ is an onset since it has an inherent coda
return true if /ɜ#{C}/ =~ arr[[0,a-1].max..a].to_s

# Other specific onset contexts
# The vowel characters "ɔ" occur in only one vowel, following a prefix;
# this means that any consonants preceding them are onsets
return true if /\A#{C}#{C}??#{T}?z/ =~ arr[a..a+4].to_s
# Certain consonant-obstruent clusters where [o] cannot be present force a
# decision to be made between coda & onset; allow consonant-obstruent
# onset sequences in these cases only
return true if
(/(f|(i#{C}))#T}?(#{UC}|ɔ|u)#{C}\Z/ =~ arr[[0,a-5].max..a].to_s) &&
(/\A#{C}?(#{O}|#{PC}|#{DC})(#{D}|#{T}|#{UV}|ɜɜ(#{UC}|#{P}\s|V))
/ =~ arr[a..a+5].to_s) && (not(/ɜ#{C}/ =~ arr[[0,a-1].max..a].to_s)) &&
(not(/#T}?v#{C}\Z/ =~ arr[[0,a-3].max..a].to_s))
return true if
(/(f|(i#{C}))#T}?(#{C}|ɔ|u)#{C}\Z/ =~ arr[[0,a-5].max..a].to_s) &&
(/\A#{C}#{O}(#{C}|#{V}|ɜɜ)(#{P}\s|V)/ =~ arr[a..a+4].to_s) &&
(not(/ɜ#{C}/ =~ arr[[0,a-1].max..a].to_s)) &&
(not(/#{UC}(#{ONS}|o)/ =~ arr[a..a+1].to_s))

# Onset contexts for characters that may be consonants or vowels
# Onset contexts for ɔ
# ɔ is an onset if it precedes a vowel with one exception where it is itself a
# vowel
return true if
(/ɜ#{UV}/ =~ arr[a..a+1].to_s) && (not(/#T}?ɜZ/ =~ arr[[0,a-
2].max..a].to_s)) && (not(/z/ =~ arr[a..a+1].to_s))

# ɔ is an onset in the following contexts since it never occurs as a coda or
# vowel following these
# ɔ is an onset when it follows these two vowel prefixes
return true if /(l|ɪ)#{C}?ɜZ/ =~ arr[[0,a-2].max..a].to_s
# ɔ is an onset when it follows one of the five diacritics, ǝ, ǝ̃, ǝ̂, ǝ̄, ǝ̆
return true if /(f|l|ɪ)#{T}?ɜZ/ =~ arr[[0,a-2].max..a].to_s
# ɔ is an onset when it follows vowel characters marking a short e vowel
return true if /u#{C}#T}?ɜZ/ =~ arr[[0,a-4].max..a].to_s
# ɔ is an onset when it follows vowel characters marking a long ɛ: vowel
return true if /i#{C}#T}?ɜZ/ =~ arr[[0,a-4].max..a].to_s
# ɔ is an onset when it follows vowel characters marking a long uɑ: vowel
return true if /i#{C}#T}?oɜZ/ =~ arr[[0,a-5].max..a].to_s

```

```

# ɹ is an onset when it follows another ɹ
return true if /ɹ/ == arr[[0,a-1].max..a].to_s

# Onset contexts for ʊ
# ʊ is an onset when it precedes a non-ambiguous vowel other than ɜ
return true if /ʊ(ɪ|ɨ|ɪ)/ == arr[a..a+1].to_s
# ʊ is an onset in the following contexts since it never occurs as a coda or
# vowel following these
# ʊ is an onset when it follows ʌ
return true if /ʌ#{C}?ʊZ/ == arr[[0,a-2].max..a].to_s
# ʊ is an onset when it follows one of the three diacritics, ̈, ̊, ̋
return true if /(̈|̊|̋)#{T}?ʊZ/ == arr[[0,a-2].max..a].to_s
# ʊ is an onset when it follows any diacritic other than ̋ and it precedes ɜ
return true if
  (/#{D}#{T}?ʊZ/ == arr[[0,a-2].max..a].to_s) && (not(/#{T}?ʊZ/ ==
    arr[[0,a-2].max..a].to_s)) && (/ɜ/ == arr[a..a+1].to_s)
# ʊ is an onset if it follows the ̋ diacritic but there is no ɪ prefix preceding
# it
return true if
  (/#{T}?ʊZ/ == arr[[0,a-2].max..a].to_s) && (not(/#{C}#{C}#{T}?ʊZ/
    == arr[[0,a-5].max..a].to_s))
# ʊ is an onset if it follows another ʊ (i.e. the vowel characters marking a
# long ia: vowel)
return true if /ʊʊ/ == arr[[0,a-1].max..a].to_s
# ʊ is an onset if it follows the vowel characters marking a short ɔ vowel
return true if /#{C}#{T}?ʊʊZ/ == arr[[0,a-4].max..a].to_s
# ʊ is an onset if it would otherwise be a coda following the unwritten [o]
# vowel
return true if
  (/(((#{NP}|^)#{C})|#{D}|#{T}|#{V}|_)(#{UC}|_)#{T}?ʊZ/ ==
    arr[[0,a-4].max..a].to_s) && (not(/_#T}?ʊZ/ == arr[[0,a-
      3].max..a].to_s))
# ʊ is an onset if it follows ɹ in the same context above for any other
# consonant, as long as ɹ is not a vowel
return true if
  (/(((#{NP}|^)#{C})|#{D}|#{T}|#{V})_#T}?ʊZ/ == arr[[0,a-
    4].max..a].to_s) && (not(/_#T}?ʊZ/ == arr[[0,a-2].max..a].to_s))
# ʊ is an onset if it follows a ɹ that is preceded by vowel characters that
# indicate ɹ is not a vowel (i.e. as long as there is no ɹ preceding it)
return true if
  (/({D}|#{UV}|_)#T}?ʊZ/ == arr[[0,a-4].max..a].to_s) &&
  (not(/#{T}?ʊZ/ == arr[[0,a-3].max..a].to_s))

# Onset contexts for ɐ
# ɐ is an onset when following a vowel prefix other than ɪ
return true if
  (/#{P}#{C}#{T}?ɐZ/ == arr[[0,a-3].max..a].to_s) &&
  (not(/#{C}#{T}?ɐZ/ == arr[[0,a-3].max..a].to_s))

```

```

# ๑ is an onset when it precedes a vowel or diacritic except in two cases
return true if
  (/๑(#{UV}|#{D})/ =~ arr[a..a+1].to_s) &&
  (not((/#{C}?#{C}?#{T}?๑\Z/ =~ arr[[0,a-5].max..a].to_s) && (/๑z/ =~
    arr[a..a+1].to_s)))
# ๑ is an onset when it follows a non-ambiguous vowel other than ๐
return true if /(๑|๑|๑)๑/ =~ arr[[0,a-1].max..a].to_s
# ๑ is an onset when it precedes a ๑๒ sequence
return true if /๑๑๒/ =~ arr[a..a+2].to_s
# ๑ is an onset following any diacritic other than "๑" and "๑"
return true if /(๑|๑|๑)#{T}?๑\Z/ =~ arr[[0,a-2].max..a].to_s
# Contexts involving ๑
# A (non-๑) consonant is an onset when it precedes ๑๑, as long as the
# second ๑ isn't an onset
return true if
  (/#{C}๑๑/ =~ arr[a..a+2].to_s) &&
  (not(^(A#{C}๑๑(#{D}|#{T}|#{UV}|๑๑(#{UC}|#{P}|s|V))/ =~
    arr[a..a+6].to_s)) && (not(/๑/ =~ arr[a].to_s))
# Other onset contexts involving ambiguous characters
# If an unambiguous consonant precedes a ๑-vprefix sequence, the ๑ must
# be a vowel, and so the consonant must be an onset, in turn
return true if
  (/#{C}๑(#{P}|s|V)/ =~ arr[a..a+2].to_s) && (not(/๑๑/ =~ arr[[0,a-
    1].max..a].to_s))
# If a consonant precedes a ๑๑ sequence and ๑ is in coda position,
# then the consonant is an onset
return true if /#{C}๑๑(#{P}|s|V)/ =~ arr[a..a+3].to_s
# If a consonant precedes a ๑๒ sequence, then the ๒ must be an onset, and
# so ๑ must be a vowel, and in turn, the consonant is an onset
return true if /#{C}๑๒/ =~ arr[a..a+2].to_s
return false
end

```

This method attempts to determine, on the basis of the context, if the current character
 # cannot be an onset. This is used in parsing; it returns true if the character cannot be an
 # onset; false otherwise.

```

def Thai_syllable.cannot_be_onset?(arr,a)
  # A character that is not a consonant cannot be an onset
  return true if (not(/#{C}/ =~ arr[a].to_s))
  # ๑ is either a vowel or coda when it follows a consonant and precedes another ๑ in
  # an onset position
  return true if
    (/#{C}#{T}?๑\Z/ =~ arr[[0,a-2].max..a].to_s) && (/๑๑/ =~
      arr[a..a+1].to_s) && (not(^(A๑๑(#{D}|#{T}|#{UV}|๑๑(#{UC}|#{P}|s|V))/ =~
        arr[a..a+5].to_s))

```

```

return true if /#{C}#{T}?ᵿZ/ =~ arr[[0,a-3].max..a].to_s && (not(/ᵿ/ =~
arr[[0,a-1].max..a].to_s)) &&
(not(/Aᵿ(#{D}|#{T}|#{UV})|ᵿ(#{UC}|#{P}|s|V)/ =~ arr[a..a+4].to_s))
# ᵿ is not an onset if it's not preceded by a vprefix and is not followed by any
# material that can provide a rime
return true if
(not(/#{P}#{C}?#{T}?ᵿZ/ =~ arr[[0,a-3].max..a].to_s)) && (/Aᵿ(#{P}|s|V)/
=~ arr[a..a+1].to_s)
# ᵿ is not an onset if it is separated from a following word boundary by an even
# number of unambiguous consonants (general sonorant coda environment)
return true if
(/Aᵿ(#{UC}#{T}?#{UC})*#{P}|s|V/ =~ arr[a..arr.length-1].to_s) &&
(not(/Aᵿ(#{UC}#{T}?#{UC})*#{UC}#{T}?#{ONS}/ =~ arr[a..arr.length-
1].to_s)) && (not(/Aᵿ(#{UC}#{T})*#{O}#{T}?#{US}#{UC}/ =~
arr[a..arr.length-1].to_s)) && (not(/ᵿ(#{P}|s|V)/ =~ arr[a..a+1].to_s))
# ᵿ is not an onset following any vprefix-C-C sequence
return true if
(/#{P}#{C}#{C}#{T}?ᵿZ/ =~ arr[[0,a-4].max..a].to_s) &&
(/Aᵿ(#{UC}#{T}?#{UC})*#{O}(#{D}|#{T}|#{UV})|ᵿ(#{UC}|#{P}|s|V)/ =~
arr[a..arr.length-1].to_s) && (not(/Aᵿ(#{UC}#{UC})*#{UC}#{ONS}/ =~
arr[a..arr.length-1].to_s)) &&
(not(/Aᵿ(#{UC}#{T})*#{O}#{T}?#{US}#{UC}/ =~ arr[a..arr.length-1].to_s))
return true if (/#{P}#{C}#{C}#{T}?ᵿZ/ =~ arr[[0,a-4].max..a].to_s) &&
(/ᵿᵿ/ =~ arr[a..a+1].to_s)
# ᵿ cannot be an onset when it precedes another ᵿ
return true if /ᵿᵿ/ =~ arr[a..a+1].to_s
return false
end

```

This method filters out cases where an impossible onset cluster would be built. It
checks whether the cluster is an attested cluster and prevents certain written consonant
sequences that appear to be clusters but are not, due to the absence of any vowel
marking other than a prefix.

```
def Thai_syllable.cluster?(arr,a)
```

```

# A consonant that would not normally be a C2 can be when only ᵿ or ᵿ separate it
# from the end of a word

```

```
if /A#(#{UC})ᵿᵿ(#{P}|s|V)/ =~ arr[a..a+2].to_s then
```

```
  return true
```

```
# ᵿ cannot be C2 in a cluster in a syllable with the unwritten [o] vowel
```

```
elsif
```

```
  (/({NP}|^)#(#{C}#{T}?ᵿZ/ =~ arr[[0,a-3].max..a].to_s) && (/ᵿ(#{UC})|ᵿ/ =~
```

```
arr[a..a+1].to_s) && (not(/ᵿᵿ(#{UC}|#{P}|V|s)/ =~ arr[a..a+3].to_s)) then
```

```
    return false
```

```
# A consonant cannot be C2 in a cluster in a syllable with the epenthetic [a] vowel
```

```
elsif
```

```

(not(/#{P}#{C}#{C}/ =~ arr[[0,a-2].max..a].to_s)) &&
  (/\A#{C}(#{C}|#{PC}|#{DC})(#{D}|#{T}|#{UV}|๓(#{UC}|#{P}|s|V))/ =~
    arr[a..a+3].to_s) then
  return false
# A consonant cannot be C2 in a cluster if it would result in some combination of
# vowel characters that is impossible
elsif
  (/#{C}#{C}/ =~ arr[[0,a-2].max..a].to_s) && (not(/A#{C}((#{T}?๓)(#{T}?๓))/
    =~ arr[a..a+3].to_s)) then
  return false
elsif
  (/#{C}#{C}/ =~ arr[[0,a-2].max..a].to_s) && (/\A#{C}#{T}?(\u{1}|u{0}|#D))/ =~
    arr[a..a+2].to_s) then
  return false
elsif
  (/u#{C}#{C}/ =~ arr[[0,a-2].max..a].to_s) && (/#{C}#{D}/ =~ arr[a..a+1].to_s)
  && (not(/#{C}#/ =~ arr[a..a+1].to_s)) then
  return false
elsif
  ((/#{PC}/ =~ arr[a-1..a].to_s) || (/#{DC}/ =~ arr[a-1..a].to_s)) &&
  (not((/(\u{1}|u{0})#{C}#{C}/ =~ arr[[0,a-2].max..a].to_s) &&
    (/\A#{C}(#{D}|#{UV}|๓#{C}(#{D}|#{T}))/ =~ arr[a..a+4].to_s))) &&
  (not(/i#{C}#{C}(\u{1}|u{0})#{D}))/ =~ arr[[0,a-2].max..a+1].to_s)) && ((not(/๓๓/ =~
    arr[a..a+1].to_s)) || (/\A๓๓(#{D}|#{T}|#{UV}|๓๓(#{UC}|#{P}|s|V))/ =~
    arr[a..a+5].to_s)) then
  return true
else
  return false
end
end
end

```

This method attempts to determine, on the basis of the context, if the current character
 # must be a vowel. This is used in parsing ambiguous characters that could be either
 # vowels or consonants; it returns true if the character must be a vowel; false otherwise.

```

def Thai_syllable.must_be_vowel?(arr,a)
  _ = arr[a]
  # If the character is a non-ambiguous vowel character, return true
  return true if /#{UV}/ =~ arr[a].to_s
  # ๓๓ is a vowel whenever the ๓'s appear consecutively and the second is clearly not
  # an onset
  return true if
    (/๓๓/ =~ arr[[0,a-1].max..a].to_s) &&
    (not(/A๓(#{D}|#{T}|#{UV}|๓(#{UC}|#{P}|s|V))/ =~ arr[a..a+4].to_s)) &&
    (not(/๓๓๓/ =~ arr[[0,a-2].max..a].to_s))
  return true if

```



```

(/ɿ/ =~ arr[a..a+1].to_s) &&
(not(/^Aɿ{D}|#{T}|#{UV}|ɿ{UC}|#{P}|s|V)/ =~ arr[a..a+5].to_s))
# Vowel contexts for ɿ
# This is the only specific context where ɿ is a vowel when it's followed by
# another vowel; it also cannot be a coda here
return true if
(/#{T}?ɿZ/ =~ arr[[0,a-2].max..a].to_s) && (/ɿ/ =~ arr[a..a+1].to_s)
# ɿ is a vowel when it follows the diacritic "ɿ" as long as it is not in a possible
# onset-context
return true if
(/#{T}?ɿZ/ =~ arr[[0,a-2].max..a].to_s) && (/ɿ{P}|s|V)/ =~ arr[a..a+1].to_s)
return true if
(/#{T}?ɿZ/ =~ arr[[0,a-2].max..a].to_s) &&
(/^Aɿ{C}|#{D}|#{T}|#{UV}|ɿ{UC}|#{P}|s|V)/ =~ arr[a..a+6].to_s)
# Vowel contexts for ʊ
# ʊ is a vowel when it follows ɿ and the ɿ diacritic
return true if /#{C}#{T}?ʊZ/ =~ arr[[0,a-4].max..a].to_s
return true if
(/#{C}#{C}#{T}?ʊZ/ =~ arr[[0,a-5].max..a].to_s) &&
(/^Aʊ{C}|#{C}|#{D}|#{T}|#{UV}|ɿ{UC}|#{P}|s|V)/ =~ arr[a..a+7].to_s)
return true if
(/#{C}#{C}#{T}?ʊZ/ =~ arr[[0,a-5].max..a].to_s) && (/ʊ{P}|s|V)/ =~
arr[a..a+1].to_s)
# Vowel contexts for ə
# ə is a vowel when it follows the ɿ diacritic
return true if /#{T}?əZ/ =~ arr[[0,a-2].max..a].to_s
# ə is a vowel when it is the final character in a syllable and is preceded by
# a character that is not a vowel prefix (in which case it would be an onset)
return true if
(/(^{NP}|^){ə}Z/ =~ arr[[0,a-1].max..a].to_s) && (/ə{P}|s|V)/ =~
arr[a..a+1].to_s)
# ə is a vowel when it is the final character in a syllable and is preceded by
# a tone-marked consonant that is not preceded by a vowel prefix
return true if /(^{NP}|^){C}#{T}əZ/ =~ arr[[0,a-4].max..a].to_s &&
(/ə{P}|s|V)/ =~ arr[a..a+1].to_s)
# ə is a vowel when it precedes ʊ, in its coda environments (these two can
# form an onset cluster)
return true if /əʊ{P}|s|V/ =~ arr[a..a+2].to_s
return true if
(/^Aəʊ{C}|#{D}|#{T}|#{UV}|ɿ{UC}|#{P}|s|V)/ =~ arr[a..a+7].to_s) &&
(not(/^Aəʊ{C}|ɿ{D}|#{T}|#{UV}|ɿ{UC}|#{P}|s|V)/ =~ arr[a..a+9].to_s))
&& (not(/əʊəZ/ =~ arr[[0,a-1].max..a+3].to_s))
return false
end

```

This method attempts to determine, on the basis of the context, if the current character

cannot be a vowel. This is used in parsing ambiguous characters that could be either
vowels or consonants; it returns true if the character cannot be a vowel; false otherwise.

```
def Thai_syllable.cannot_be_vowel?(arr,a)
  _ = arr[a]
  # Stating the obvious
  return true if not(/#{V}/ =~ arr[a].to_s)
  # Any character following ๑ cannot be a vowel, since ๑ has an inherent vowel
  return true if /๑#{T}?#{_}\Z/ =~ arr[[0,a-2].max..a].to_s
  # ๒ and ๓ are not vowels if they follow a v-prefix (optionally with a consonant in
  # between)
  return true if /#{P}#{C}?#{T}?(๒|๓)\Z/ =~ arr[[0,a-3].max..a].to_s
  # ๔ is not a vowel if it doesn't follow the ๕ diacritic
  return true if (/๔/ =~ arr[a].to_s) && (not(/#{T}?๔\Z/ =~ arr[[0,a-2].max..a].to_s))
  # ๖ is not a vowel if it's not preceded by ๗ and not followed by anything that can
  # possibly be a coda
  return true if
    (not(/#{T}?๖\Z/ =~ arr[[0,a-2].max..a].to_s)) && (/\A๖(#{P}|\s|\V)/ =~
    arr[a..a+1].to_s)
  # ๗ is not a vowel if it's preceded by a diacritic other than ๘ or a vowel
  return true if
    (/({UV}|#{D})#{T}?๗\Z/ =~ arr[[0,a-2].max..a].to_s) && (not(/#{T}?๗\Z/ =~
    arr[[0,a-2].max..a].to_s))
  # ๘ is not a vowel if it's preceded by a prefix-onset combination
  return true if /#{P}(#{C}|#{PC}|#{DC})๘\Z/ =~ arr[[0,a-3].max..a].to_s
  # ๙ is not a vowel if it is neither preceded nor followed by another "๙"
  return true if
    (/๙/ =~ arr[a].to_s) && (not(/๙๙/ =~ arr[a..a+1].to_s)) && (not(/๙๙/ =~ arr[[0,a-
    1].max..a].to_s))
  # ๙ is not a vowel if it is followed by an onset and not preceded by another ๙
  return true if
    (/\A๙#{C}(#{D}|#{T}|#{UV}|๙๙(#{UC}|#{P}|\s|\V))/ =~ arr[a..a+4].to_s) &&
    (not(/๙๙/ =~ arr[[0,a-1].max..a].to_s))
  return false
end
```

This method attempts to determine, on the basis of the context, if the current
character must be a coda. This is used in parsing; it returns true if the character must be
a coda; false otherwise.

```
def Thai_syllable.must_be_coda?(arr,a)
  _ = arr[a]
  # Filter out the non-coda consonants first
  return false if /({ONS}|๐)/ =~ arr[a].to_s
  # Additionally, none of the coda contexts apply if the consonant is preceded by a vowel
  # prefix; even with an intervening consonant, it may be an onset; this is not true if the
  # current character is the 2nd member in a ๑๒ vowel
  return false if
```

```

(not((/{NP}|^){NP}|^){T}?(/{UC}|ᵛ)Z/ =~ arr[[0,a-3].max..a].to_s) && (not(/ᵛ/
  =~ arr[[0,a-1].max..a].to_s))))
# Finally, none of the coda contexts apply if the consonant is preceded by a consonant
# that must be a coda itself; this includes consonants preceded by vowel characters that
# mandate closed syllables; this is not true, however, if the preceding consonant is ᵛ
return false if ((/{T}?#{C}#{C}Z/ =~ arr[[0,a-3].max..a].to_s) ||
  (/{P}#{C}#{T}?#{C}#{C}Z/ =~ arr[[0,a-5].max..a].to_s) || (/ᵛ#{C}#{C}Z/ =~
  arr[[0,a-4].max..a].to_s) || (/#{C}#{T}?#{C}#{C}Z/ =~ arr[[0,a-5].max..a].to_s) ||
  (/ᵛ#{T}?#{C}#{C}Z/ =~ arr[[0,a-3].max..a].to_s)) && (not(/ᵛ#{C}/ =~ arr[[0,a-
  1].max..a].to_s))
# General coda contexts
# An unambiguous consonant is a coda when it precedes a consonant that must be
# an onset and when it cannot be the first member of an onset cluster (only
# obstruent-sonorant sequences allowed)
return true if
  /\A#{UC}#{O}#{T}?#{C})*#{O}#{D}|#{T}|#{UV}|ᵛ(#{UC}|#{P}|s|V)/
  =~ arr[a..arr.length-1].to_s &&
  (not(/\A#{UC}#{O}#{T}?#{C})*#{O}#{T}?#{ONS}/ =~ arr[a..arr.length-
  1].to_s)) && (not(/\A#{UC}#{UC}#{T})*#{O}#{T}?#{US}#{UC}/ =~
  arr[a..arr.length-1].to_s)) && (not(/ᵛ#{C}/ =~ arr[[0,a-1].max..a].to_s))
return true if /\A#{UC}#{O}#{T}?#{C})*#{P}|s|V/ =~ arr[a..arr.length-1].to_s
&& (not(/\A#{UC}#{O}#{T}?#{C})*#{O}#{T}?#{ONS}/ =~ arr[a..arr.length-
1].to_s)) && (not(/\A#{UC}#{UC}#{T})*#{O}#{T}?#{US}#{UC}/ =~
arr[a..arr.length-1].to_s)) && (not(/ᵛ#{C}/ =~ arr[[0,a-1].max..a].to_s))
# A sonorant is a coda in the same context as above with slightly looser
# requirements in a following consonant sequence
return true if
  /\A#{US}#{UC}#{T}?#{UC})*#{O}#{D}|#{T}|#{UV}|ᵛ(#{UC}|#{P}|s|V)/
  =~ arr[a..arr.length-1].to_s &&
  (not(/\A#{US}#{UC}#{T}?#{UC})*#{UC}#{T}?#{ONS}/ =~
  arr[a..arr.length-1].to_s)) &&
  (not(/\A#{US}#{UC}#{T})*#{O}#{T}?#{US}#{UC}/ =~ arr[a..arr.length-
  1].to_s))
return true if
  /\A#{US}#{UC}#{T}?#{UC})*#{UC}#{T}?#{S}#{S}#{D}|#{T}|#{UV}|ᵛ(
  #{UC}|#{P}|s|V)/ =~ arr[a..arr.length-1].to_s &&
  (not(/\A#{US}#{UC}#{T}?#{UC})*#{UC}#{T}?#{ONS}/ =~
  arr[a..arr.length-1].to_s)) &&
  (not(/\A#{US}#{UC}#{T})*#{O}#{T}?#{US}#{UC}/ =~ arr[a..arr.length-
  1].to_s))
return true if
  /\A#{US}#{UC}#{T}?#{UC})*#{P}|s|V/ =~ arr[a..arr.length-1].to_s &&
  (not(/\A#{US}#{UC}#{T}?#{UC})*#{UC}#{T}?#{ONS}/ =~
  arr[a..arr.length-1].to_s)) &&
  (not(/\A#{US}#{UC}#{T})*#{O}#{T}?#{US}#{UC}/ =~ arr[a..arr.length-
  1].to_s))

```

```

# If the consonant is in 2nd position in a word, preceded only by another
# consonant, then the requirements on what constitutes a following onset are less
# strict
return true if
  ((/(\s|V){C}#{T}?(#{UC}|ᵿ)Z/ =~ arr[[0,a-3].max..a].to_s) || (a == 1)) &&
  (/\A(#{UC}|ᵿ)(#{UC}|ᵿ|ᵿ)?#{T}#{C}#{O}(#{D}|#{T}|#{UV}|ᵿ|ᵿᵿ#{C}(#{D}|#{T}))/ =~ arr[a..a+8].to_s) &&
  (not(/(#{UC}|ᵿ)/ =~ arr[[0,a-1].max..a].to_s))
  && (not(/\A(#{UC}|ᵿ)(#{UC}|ᵿ|ᵿ)?#{T}?ᵿz/ =~ arr[a..a+4].to_s)) &&
  (not(/\A(#{UC}|ᵿ)(#{UC}|ᵿ|ᵿ)?#{T}?ᵿᵿ/ =~ arr[a..a+4].to_s)) &&
  (not(/\A(#{UC}|ᵿ)#{C}#{T}ᵿᵿ(#{D}|#{T}|#{UV}|ᵿᵿ(#{UC}|#{P}|ᵿ|ᵿ))/ =~
  arr[a..a+8].to_s)) && (not(/ᵿᵿ/ =~ arr[a..a+1].to_s))

# Certain vowel diacritics mandate a closed syllable; a consonant following them
# must be a coda
  return true if /#{T}?ᵿ#{C}Z/ =~ arr[[0,a-3].max..a].to_s
  return true if /#{T}?#{C}Z/ =~ arr[[0,a-2].max..a].to_s
  return true if /#{C}#{T}#{C}Z/ =~ arr[[0,a-4].max..a].to_s

# A consonant (other than ᵿ, which can be a vowel here) that follows the ᵿ
# sequence is a coda since it marks preceding closed syllables only
  return true if
    (/#{T}?#{C}Z/ =~ arr[[0,a-2].max..a].to_s) && (not(/ᵿ/ =~ arr[a].to_s))

# If an unambiguous consonant follows a tone mark, but there is no vowel
# character, then it must be a coda in an unwritten [o] vowel
  return true if
    (/({NP}|^)(#{NP}|^){C}#{T}#{UC}Z/ =~ arr[[0,a-4].max..a].to_s)

# If an unambiguous consonant is not in a syllable with a vowel character and it
# precedes a consonant that must be an onset, then it is a coda in a syllable with
# an unwritten [o] vowel
  return true if
    (/({NP}|^)(#{UC}|ᵿ|ᵿ)(#{UC}|ᵿ)Z/ =~ arr[[0,a-2].max..a].to_s) &&
    (/\A(#{UC}|ᵿ)#{C}(#{D}|#{T}|#{UV}|ᵿ|ᵿᵿ#{C}(#{D}|#{T}))/ =~
    arr[a..a+5].to_s) && (not(/({PC}|#{DC})/ =~ arr[a..a+1].to_s)) &&
    (not(/({O}|#{S})/ =~ arr[a..a+1].to_s)) && (not(/(#{UC}|ᵿ)(ᵿᵿ|ᵿᵿ|ᵿᵿ)/ =~
    arr[a..a+2].to_s))

# Coda contexts for characters that may be consonants or vowels
# Coda contexts for ᵿ
  # ᵿ is not a vowel if it's in a syllable with a vprefix; it cannot be an onset either
  # in the general environment for sonorant codas above; hence it must be a coda
  return true if
    (/({P}|#{C}#{T}?ᵿ/ =~ arr[[0,a-3].max..a].to_s) &&
    (/\Aᵿ(#{UC}#{T}?#{UC})*#{O}(#{D}|#{T}|#{UV}|ᵿᵿ(#{UC}|#{P}|ᵿ|ᵿ|ᵿ)/ =~
    arr[a..arr.length-1].to_s) &&
    (not(/\Aᵿ(#{UC}#{T}?#{UC})*#{UC}#{T}#{ONS}/ =~
    arr[a..arr.length-1].to_s)) &&
    (not(/\Aᵿ(#{UC}#{T})*#{O}#{T}#{US}#{UC}/ =~ arr[a..arr.length-
    1].to_s))

  # ᵿ is a coda following ᵿ, when it's not an onset

```

```

return true if
  (/ɹ/ =~ arr[[0,a-1].max..a].to_s) &&
  (/\Aɹ(\#{UC}\#{T}?\#{UC})*\#{O}(\#{D}|\#{T}|\#{UV})|ɹɹ(\#{UC}|\#{P})|s\|
  /)/ =~ arr[a..arr.length-1].to_s) &&
  (not(/\Aɹ(\#{UC}\#{T}?\#{UC})*\#{UC}\#{T}?\#{ONS})/ =~
  arr[a..arr.length-1].to_s)) &&
  (not(/\Aɹ(\#{UC}\#{T}?)*\#{O}\#{T}?\#{US}\#{UC})/ =~ arr[a..arr.length-
  1].to_s))
return true if /ɹ(ɹ|ʊ|ə)/ =~ arr[[0,a-1].max..a+1].to_s
# ɹ is a coda following ɹ̥, when it's not an onset
return true if
  (/#\{T}?\Z/ =~ arr[[0,a-2].max..a].to_s) &&
  (/\Aɹ(\#{UC}\#{T}?\#{UC})*\#{O}(\#{D}|\#{T}|\#{UV})|ɹɹ(\#{UC}|\#{P})|s\|
  /)/ =~ arr[a..arr.length-1].to_s) &&
  (not(/\Aɹ(\#{UC}\#{T}?\#{UC})*\#{UC}\#{T}?\#{ONS})/ =~
  arr[a..arr.length-1].to_s)) &&
  (not(/\Aɹ(\#{UC}\#{T}?)*\#{O}\#{T}?\#{US}\#{UC})/ =~ arr[a..arr.length-
  1].to_s))
return true if
  (/#\{T}?\Z/ =~ arr[[0,a-2].max..a].to_s) && (/ɹ(ɹ|ʊ|ə)/ =~
  arr[a..a+1].to_s)
# ɹ is a coda following ɹ̥ʊ, when it's not an onset
return true if
  (/#\{C}\#{T}?\Z/ =~ arr[[0,a-5].max..a].to_s) &&
  (/\Aɹ(\#{UC}\#{T}?\#{UC})*\#{O}(\#{D}|\#{T}|\#{UV})|ɹɹ(\#{UC}|\#{P})|s\|
  /)/ =~ arr[a..arr.length-1].to_s) &&
  (not(/\Aɹ(\#{UC}\#{T}?\#{UC})*\#{UC}\#{T}?\#{ONS})/ =~
  arr[a..arr.length-1].to_s)) &&
  (not(/\Aɹ(\#{UC}\#{T}?)*\#{O}\#{T}?\#{US}\#{UC})/ =~ arr[a..arr.length-
  1].to_s))
return true if
  (/#\{C}\#{T}?\Z/ =~ arr[[0,a-5].max..a].to_s) && (/ɹ(ɹ|ʊ|ə)/ =~
  arr[a..a+1].to_s)
# Coda contexts for ʊ
# ʊ is a coda in the general coda context for sonorants if it's not preceded
# by a vprefix (onset context) and if it's not preceded by the ɪ̥ (vowel
# context) & it's not preceded by a non-ambiguous consonant (a-
# epenthetic onset in this case)
return true if
  (not(/(\#{T}?)\#{P})ʊ\Z/ =~ arr[[0,a-2].max..a].to_s)) &&
  (/\Aʊ(\#{UC}\#{T}?\#{UC})*\#{O}(\#{D}|\#{T}|\#{UV})|ɹɹ(\#{UC}|\#{P})|s\|
  /)/ =~ arr[a..arr.length-1].to_s) && (not(/#\{UC}ʊ/ =~ arr[[0,a-
  1].max..a].to_s)) &&
  (not(/\Aʊ(\#{UC}\#{T}?\#{UC})*\#{UC}\#{T}?\#{ONS})/ =~
  arr[a..arr.length-1].to_s)) &&

```

```

(not(/Au(#{UC}#{T}?)*#{O}#{T}#{US}#{UC}/=~ arr[a..arr.length-1].to_s))
return true if (not(/(#{T}?)|#{P}|#{UC})u\Z/ =~ arr[[0,a-2].max..a].to_s))
&& (/Au(#{UC}#{T}#{UC})*#{P}|s|V/ =~ arr[a..arr.length-1].to_s)
&& (not(/Au(#{UC}#{T}#{UC})*#{UC}#{T}#{ONS}/=~ arr[a..arr.length-1].to_s)) &&
(not(/Au(#{UC}#{T}?)*#{O}#{T}#{US}#{UC}/=~ arr[a..arr.length-1].to_s))
# u is a coda when preceding ɹ or u or ə in the following contexts
# u is a coda following the iɕə vowel
return true if
(/#{C}#{C}#{T}?u\Z/ =~ arr[[0,a-6].max..a].to_s) && (/u(ɹ|u|ə)/ =~ arr[a..a+1].to_s)
# u is a coda following certain vowel-diacritics
return true if
(/(ɥ|ɥ̥)#{T}?u\Z/ =~ arr[[0,a-2].max..a].to_s) && (/u(ɹ|u|ə)/ =~ arr[a..a+1].to_s)
# u is a coda following ɹ
return true if /u(ɹ|u|ə)/ =~ arr[[0,a-1].max..a+1].to_s
# u is a coda following ɹ
return true if /u(ɹ|u|ə)/ =~ arr[[0,a-1].max..a+1].to_s
# u is a coda following a consonant-tone-ə sequence (əu is a possible onset cluster)
return true if
(/#{UC}#{T}u\Z/ =~ arr[[0,a-3].max..a].to_s) && (/u(ɹ|u|ə)/ =~ arr[a..a+1].to_s)
# Coda contexts for ɹ
# If ɹ follows a tone mark, but there is no vowel marked, then it must be
# a coda unless it is part of a ɹɹ vowel
return true if
(/(#{NP}|^)(#{NP}|^)#C#{T}ɹ\Z/ =~ arr[[0,a-4].max..a].to_s) &&
((not(/ɹɹ/ =~ arr[a..a+1].to_s)) ||
(/Aɹ(#{D}|#{T}|#{UV})ɹ(#{UC}#{P}|s|V)/ =~ arr[a..a+5].to_s))
# ɹ is a coda in the general contexts for sonorants if it's not preceded by
# another ɹ
return true if
(/Aɹ(#{UC}#{T}#{UC})*#{O}(#{D}|#{T}|#{UV})ɹ(#{UC}#{P}|s|V)/ =~ arr[a..arr.length-1].to_s) &&
(not(/Aɹ(#{UC}#{T}#{UC})*#{UC}#{T}#{ONS}/ =~ arr[a..arr.length-1].to_s)) &&
(not(/Aɹ(#{UC}#{T}?)*#{O}#{T}#{US}#{UC}/ =~ arr[a..arr.length-1].to_s))
return true if
(/Aɹ(#{UC}#{T}#{UC})*#{UC}#{T}#{S}#{S}(#{D}|#{T}|#{UV})ɹ(#{UC}#{P}|s|V)/ =~ arr[a..arr.length-1].to_s) &&
(not(/Aɹ(#{UC}#{T}#{UC})*#{UC}#{T}#{ONS}/ =~

```

```

arr[a..arr.length-1].to_s)) &&
(not(/\A๓(\#{UC}\#{T})*\#{O}\#{T}?\#{US}\#{UC}/ =~ arr[a..arr.length-
1].to_s))
return true if
(/\A๓(\#{UC}\#{T}?\#{UC})*(\#{UC}\#{T}?(#\{C\}#\{V\}))?(#\{P\}|\s|\V)/ =~
arr[a..arr.length-1].to_s) &&
(not(/\A๓(\#{UC}\#{T}?\#{UC})*\#{UC}\#{T}?\#{ONS}/ =~
arr[a..arr.length-1].to_s)) &&
(not(/\A๓(\#{UC}\#{T})*\#{O}\#{T}?\#{US}\#{UC}/ =~ arr[a..arr.length-
1].to_s))
return false
end

# This method attempts to determine, on the basis of the context, if the current character
# cannot be a coda. This is used in parsing ambiguous characters that could be either
# vowels or consonants; it returns true if the character cannot be a coda; false otherwise.
def Thai_syllable.cannot_be_coda?(arr,a)
  _ = arr[a]
  # If the character follows ๑, then it is not a coda
  return true if /\#{C}/ =~ arr[[0,a-1].max..a].to_s
  # If the character is not a consonant, then it cannot be a coda
  return true if (not(/#\{C}/ =~ arr[a].to_s))
  # If the character is one that is never a coda, then return true
  return true if arr[a] == "๐"
  return true if /\#{ONS}/ =~ arr[a].to_s
  # ๑ cannot be a coda following the unwritten [o] vowel); it may be a
  # codafollowing ๐ in the [ia:] vowel
  return true if
    /(((#\{NP\}|\^)\#{C})\#{V}|\#{D}|\#{T})\#{C}\#{T}?๑\Z/ =~ arr[[0,a-4].max..a].to_s
    && (not(/#\{C}\#{C}\#{T}?๐\Z/ =~ arr[[0,a-6].max..a].to_s))
  return false
end

# Reconstructs the Thai script string representing the syllable, from the constituents.
def to_ts
  return @v_prefix + @onset + @v_diacritic + @tone + @vowel + @coda
end

# Returns a string with the contents of the syllable broken into labeled constituents, with
# the characters for each constituent placed between slashes. NOTE: diacritic characters,
# like tone, will probably display as diacritics on the preceding slash.
def to_ts_verbose
  return "vprefix:/#\{@v_prefix}/ onset:/#\{@onset}/ vdiacritic:/#\{@v_diacritic}/
  tone:/#\{@tone}/ vowel:/#\{@vowel}/ coda:/#\{@coda}/"
end

```

```

# Reconstructs the translated JPA string representing the syllable, from the constituents.
def to_jpa
  return @jonset + @jvowel + @jlength + @jcoda + @jtone.to_s
end

# Returns a string with the contents of the translated JPA syllable broken into labeled
# constituents, with the characters for each constituent placed between slashes.
def to_jpa_verbose
  return "onset:#{@jonset}/ vowel:#{@jvowel}/ length:#{@jlength}/
  coda:#{@jcoda}/ tone:#{@jtone}/"
end

# Reconstructs the translated JPA string representing the syllable, from the constituents.
def to_ipa
  return @ipa_onset + @ipa_vowel + @ipa_tone + @ipa_length + @ipa_coda
end

# Returns true if Thai character _tchar_ is possibly a vocalic prefix.
# NOTE: _tchar_ is expected to be a string of length 1.
def Thai_syllable.v_prefix?(tchar)
  return "true" if /#{P}/ =~ tchar
end

# Returns true if Thai character _tchar_ is a consonant; false otherwise.
def Thai_syllable.consonant?(tchar)
  return "true" if /#{C}/ =~ tchar
end

# Returns true if Thai character _tchar_ is a tone marker; false otherwise.
def Thai_syllable.tone?(tchar)
  return "true" if /#{T}/ =~ tchar
end

# Returns true if Thai character _tchar_ is a possible (non-prefix) vowel character; false
# otherwise.
def Thai_syllable.vowel?(tchar)
  return "true" if /#{V}/ =~ tchar
end

# Returns true if Thai character _tchar_ is a possible vowel diacritic character; false
# otherwise.
def Thai_syllable.v_diacritic?(tchar)
  return "true" if /#{D}/ =~ tchar
end

# Translates Thai characters in onset position to JPA

```



```

def to_jpa_onset(tchar)
  ans = case tchar
  when "ᵿ" then "P"
  when "ᵿ" then "P"
  when "ᵿ" then "P"
  when "ᵿ" then "p"
  when "ᵿ" then "b"
  when "ᵿ" then "m"
  when "ᵿ" then "w"
  when "ᵿ" then "f"
  when "ᵿ" then "f"
  when "ᵿ" then "T"
  when "ᵿ" then "T"
  when "ᵿ" then "T"
  when "ᵿ" then "T"
  when "ᵿ" then "T"
  when "ᵿ" then "t"
  when "ᵿ" then "t"
  when "ᵿ" then "d"
  when "ᵿ" then "d"
  when "ᵿ" then "s"
  when "ᵿ" then "s"
  when "ᵿ" then "s"
  when "ᵿ" then "s"
  when "ᵿ" then "l"
  when "ᵿ" then "l"
  when "ᵿ" then "r"
  when "ᵿ" then "n"
  when "ᵿ" then "n"
  when "ᵿ" then "j"
  when "ᵿ" then "j"
  when "ᵿ" then "C"
  when "ᵿ" then "C"
  when "ᵿ" then "C"
  when "ᵿ" then "c"
  when "ᵿ" then "K"
  when "ᵿ" then "K"
  when "ᵿ" then "K"
  when "ᵿ" then "K"
  when "ᵿ" then "K"
  when "ᵿ" then "k"
  when "ᵿ" then "N"
  # z marks an empty onset
  when "ᵿ" then "z"
  when "ᵿ" then "h"

```

```

when "๑" then "h"
when "ຶ" then "r"
else ""
end
return ans
end

# Translates Thai vowel characters to JPA vowel quality
def to_jpa_vowel
  return "y" if (@vowel == "ຶ")
  # The onset character "ຶ" usually comes with an implied unwritten [i] vowel; it
  # sometimes is pronounced with the [u] vowel
  return "i" if
    (@v_prefix == "") && ((@onset == "ຶ") || (@onset == "ຶຶ") || (@onset ==
      "ຶຶ")) && (@v_diacritic == "") && (@vowel == "")
  return "a" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "๑")
  return "a" if
    (@v_prefix == "") && (@v_diacritic == " ") && (@vowel == "")
  return "a" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "๑๑")
  # Epenthetic [a] vowel inserted if there is no rime material in the syllable
  return "a" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "") && (@coda
      == "")
  return "a" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "ຶ")
  return "A" if
    (@v_prefix == "u") && (@v_diacritic == "") && (@vowel == "๑")
  return "A" if
    (@v_prefix == "u") && (@v_diacritic == " ") && (@vowel == "")
  return "A" if
    (@v_prefix == "u") && (@v_diacritic == "") && (@vowel == "")
  return "O" if
    (@v_prefix == "i") && (@v_diacritic == "") && (@vowel == "๑๑")
  return "O" if
    (@v_prefix == "") && (@v_diacritic == " ") && (@vowel == "๑")
  return "O" if
    (@v_prefix == "") && (@v_diacritic == " ") && (@vowel == "")
  return "O" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "๑")
  return "e" if
    (@v_prefix == "i") && (@v_diacritic == "") && (@vowel == "๑")
  return "e" if
    (@v_prefix == "i") && (@v_diacritic == " ") && (@vowel == "")
  # Special case when there is a [j] coda

```

```

return "E" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "") && (@coda
    == "ɐ")
# General case for these vowel characters
return "e" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "") && (@coda
    != "ɐ")
return "E" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ə̃")
return "E" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "")
return "E" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ə")
return "o" if
  (@v_prefix == "ɪ") && (@v_diacritic == "") && (@vowel == "")
# Special case for the unwritten [o] vowel with "r" coda;
return "O" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "") && (@coda
    == "ɹ")
# General case for the short unwritten [o] vowel
return "o" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "") && (@coda
    != "") && (@coda != "ɹ")
return "o" if
  (@v_prefix == "ɪ") && (@v_diacritic == "") && (@vowel == "ɘ")
return "i" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "")
return "i" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "")
return "y" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "")
return "y" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "ə")
return "y" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "")
return "u" if
  (@v_prefix == "") && (@v_diacritic == "ɹ") && (@vowel == "")
return "u" if
  (@v_prefix == "") && (@v_diacritic == "ɹ") && (@vowel == "")
return "I" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ɘ̃")
return "I" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ɐ")
return "Y" if
  (@v_prefix == "l") && (@v_diacritic == "") && (@vowel == "ə̃")
return "Y" if

```

```

    (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "๑")
return "U" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "๑๕")
return "U" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "๑")
return "U" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "๑")
return "a" if
    (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "")
return "a" if
    (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "")
return "a" if
    (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "ิ")
return "a" if
    (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "ิ")
end

# Translate Thai vowel characters to JPA vowel length
def to_jpa_length (tdons)
    return "." if @vowel == "๕"
    return "." if @vowel == "๑๕"
    return "." if (@v_diacritic == "") && (@vowel == "")
    # Special case for "ิ" with [w] coda; it's marked by the presence of the v_prefix
    return "." if (@v_prefix == "ิ") && (@vowel == "ิ")
    # General case for "ิ"
    return ":" if (@v_prefix == "") && (@vowel == "ิ")
    return "." if @v_diacritic == ""
    # Special case for the [ε:] vowel; in live syllables with overt tone marking and a
    # mid- or high-class onset, the vowel is short
    return "." if
        (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "") && ((@coda
            == "") || (/#{S}\Z/ =~ @coda.to_s)) && (@tone != "") && (not(/#{L}/ =~
            tdons))
    # General case for the [ε:] vowel
    return ":" if
        (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "")
    return "." if @vowel == "๑๕"
    return ":" if (@v_diacritic == "") && (@vowel == "๑")
    # Special case for [ε:] vowel; if there is an overt tone mark, then it is a short
    # vowel
    return "." if
        (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "") && (@tone
            != "") && (@coda != "๑")
    # Otherwise it is a long vowel if there is no overt tone mark
    return ":" if
        (@v_prefix == "ิ") && (@v_diacritic == "") && (@vowel == "")

```

```

return "." if @vowel == "๑๐"
return ":" if (@v_prefix == "ิ") && (@v_diacritic == "")
return ":" if (@v_prefix == "ิ") && (@vowel == "๑")
# Special case for the unwritten [o] vowel with [r] coda
return ":" if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "") && (@coda
    == "ร")
# General case for the unwritten [o] vowel
return "." if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "") && (@coda
    != "") && (@coda != "ร")
# Epenthetic [a] vowel
return "." if
  (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "") && (@coda
    == "")
return ":" if (@v_prefix == "ิ") && (@vowel == "")
return "." if (@v_prefix == "") && (@v_diacritic == "")
return ":" if (@v_diacritic == "") && (@vowel == "")
return "." if @v_diacritic == ""
return ":" if (@v_diacritic == "") && (@vowel == "๑")
return "." if (@v_diacritic == "") && (@vowel == "")
return "." if @v_diacritic == "ํ"
return ":" if @v_diacritic == "ํ"
return "." if @vowel == "๑๐"
return ":" if @vowel == "๑"
return "." if @vowel == "๑๐"
# Special case for [j] coda
return "." if (@vowel == "จ") && (@coda == "ย")
# General case for [j] coda
return ":" if (@vowel == "จ") && (@coda != "ย")
return "." if @v_prefix == "ิ"
return "." if @v_prefix == "ิ"
# Special case for "๑" vowel
return ":" if (/#{L}/ =~ tdons) && (@tone == "๑")
# General case for "๑" vowel
return "." if @vowel == "๑"
return "." if ((@onset == "ก") || (@onset == "ขก") || (@onset == "นก"))
end

```

```

# Translates Thai tone marks to JPA given a tone-determining onset consonant _tdons_
# mid tone = 0; low tone = 1; falling tone = 2; high tone = 3; rising tone = 4

```

```
def to_jpa_tone(tdons)
```

```
  # These two tone marks indicate rising & high tone respectively
```

```
    return ("4").to_s if @tone == "๑"
```

```
    return ("3").to_s if @tone == "๒"
```

```
  # This tone mark denotes falling tone for low-class consonants but low tone for
```

```

# high- and mid-class consonants
return ("2").to_s if (/^A#{L}/ =~ tdons) && (@tone == "")
return ("1").to_s if (/^A(#{M}|#{H})/ =~ tdons) && (@tone == "")
# This tone mark denotes high tone for low-class consonants but falling tone for
# high- and mid-class consonants
return ("3").to_s if (/^A#{L}/ =~ tdons) && (@tone == "̂")
return ("2").to_s if (/^A(#{M}|#{H})/ =~ tdons) && (@tone == "̂")
# For syllables without overt tone marking
# For a "live" syllable (open with a long vowel or closed with a sonorant
# coda)
# Mid tone is pronounced in a live syllable with a low- or mid-class onset
# consonant
return ("0").to_s if
  (/^A(#{L}|#{M})/ =~ tdons) && (@tone == "") && ((/#{S}\Z/ =~
    @coda) || ((@coda == "") && (@jlength == ".") || (@vowel == "ɿ")))
# Rising tone is pronounced in a live syllable with a high-class onset
# consonant
return ("4").to_s if
  (/^A#{H}/ =~ tdons) && (@tone == "") && ((/#{S}\Z/ =~ @coda) ||
    ((@coda == "") && (@jlength == ".") || (@vowel == "ɿ")))
# For a "dead" syllable (open with a short vowel or closed with an obstruent
# coda)
# High tone is pronounced in a dead syllable with a low-class onset
# consonant and a short vowel
return ("3").to_s if
  (/^A#{L}/ =~ tdons) && (@tone == "") && (@jlength == ".") &&
  ((/#{O}\Z/ =~ @coda) || (@coda == "") || (@coda == "̂")) &&
  (not(@vowel == "ɿ"))
# Falling tone is pronounced in a dead syllable with a low-class onset
# consonant and a long vowel
return ("2").to_s if
  (/^A#{L}/ =~ tdons) && (@tone == "") && (@jlength == ".") &&
  ((/#{O}\Z/ =~ @coda) || (@coda == "") || (@coda == "̂")) &&
  (not(@vowel == "ɿ"))
# Low tone is pronounced in a dead syllable with a mid- or high-class onset
# consonant
return ("1").to_s if
  (/^A(#{M}|#{H})/ =~ tdons) && (((/#{O}\Z/ =~ @coda) || (@coda
    == "̂")) || ((@coda == "") && (@jlength == "."))) && (not(@vowel ==
    "ɿ"))
end

# Translates Thai characters in coda position to JPA
def to_jpa_coda
# Allow for an optional "ɿ" as the first member in a complex coda
return "p" if /^Aɿ?(n|ɲ|ɳ|ɰ|ɱ)/ =~ @coda

```



```

return "kh" if tchar == "K"
return "" if tchar == "z"
return "ŋ" if tchar == "N"
return "ɛ" if tchar == "A"
return "ɔ" if tchar == "O"
return "ɤ" if tchar == "E"
return "u" if tchar == "y"
return "ia" if tchar == "I"
return "ua" if tchar == "Y"
return "ua" if tchar == "U"
return ":" if tchar == ":"
return "" if tchar == "."
return "" if tchar == "0"
return "̣" if tchar == "1"
return "̣" if tchar == "2"
return "̣" if tchar == "3"
return "̣" if tchar == "4"
return tchar

end

# If a syllable is deficient in any way, this instance method returns a warning message
def check_syll
  return "All syllables must have an onset" if @onset == ""
  return "All syllables must have a JPA onset" if @jonset == ""
  return "All syllables must have a JPA vowel character" if @jvowel == ""
  return "All syllables must have a JPA vowel length" if @jlength == ""
  return "All syllables must have a JPA coda" if @jcoda == ""
  return "All syllables must have a JPA tone" if @jtone == ""
  return "Impossible onset cluster" if
    (not(/#{PC}/ =~ @onset.to_s)) && (not(/#{DC}/ =~ @onset.to_s)) &&
    (not(/#{C}/ =~ @onset.to_s))
  # This restriction is unconfirmed with the mid round vowels, although there are
  # no entries in Slayden's online dictionary
  return "No Cw cluster allowed with round vowels" if
    (/#{C}w/ =~ @jonset.to_s) && ((@jvowel == "u") || (@jvowel == "U") ||
    (@jvowel == "o") || (@jvowel == "O"))
  return "Impossible rime" if
    (((@jvowel == "A") && (@jcoda == "j")) || ((@jvowel == "e") && (@jcoda
    == "j")) || ((@jvowel == "E") && (@jcoda == "j") && (@jlength == ".")) ||
    (((@jvowel == "o") && (@jcoda == "j") && (@jlength == ".")) || ((@jvowel ==
    "i") && (@jcoda == "j")) || ((@jvowel == "y") && (@jcoda == "j") &&
    (@jlength == ".")) || ((@jvowel == "I") && (@jcoda == "j")) || ((@jvowel ==
    "Y") && (@jcoda == "j") && (@jlength == ".")) || ((@jvowel == "U") &&
    (@jcoda == "j") && (@jlength == ".")) || ((@jvowel == "A") && (@jcoda ==
    "w") && (@jlength == ".")) || ((@jvowel == "O") && (@jcoda == "w") &&
    (@jlength == ".")) || ((@jvowel == "E") && (@jcoda == "j") && (@jlength ==

```



```

        ".") || ((@jvowel == "o") && (@jcoda == "w")) || ((@jvowel == "i") &&
        (@jcoda == "w") && (@jlength == ".")) || ((@jvowel == "y") && (@jcoda ==
        "w")) || ((@jvowel == "u") && (@jcoda == "w")) || ((@jvowel == "I") &&
        (@jcoda == "w") && (@jlength == ".")) || ((@jvowel == "Y") && (@jcoda ==
        "w")) || ((@jvowel == "U") && (@jcoda == "w")))
    return "Impossible onset-vowel combination" if
        (@jonset == "w") && ((@jvowel == "Y") || (@jvowel == "y"))
    # This rule has a few exceptions
    return "C1 in onset clusters where a-epenthesis occurs cannot have written tone"
    if
        (@tone != "") && (@v_prefix == "") && (@v_diacritic == "") && (@vowel
        == "") && (@coda == "")
    # There are quite a few exceptions to this rule; still I enforce it since most
    # syllables where this could happen parse the members of this potential cluster in
    # separate syllables
    return "C1 in onset clusters where a-epenthesis occurs cannot have more than one
    consonant" if
        (/#{C}#{C}/ =~ @onset.to_s) && (not(/#{C}η/ =~ @onset.to_s)) &&
        (@v_prefix == "") && (@v_diacritic == "") && (@vowel == "") && (@coda
        == "")
    return "Vowel prefixes cannot have more than one character" if
        @v_prefix.length > 3
    return "Onsets cannot have more than two consonants" if @onset.length > 6
    return "Onsets cannot have C-obstruent clusters" if /#{C}#{O}/ =~ @onset.to_s
    return "Onsets cannot have sonorant-sonorant clusters" if
        (/#{S}#{S}/ =~ @onset.to_s) && (not(/ʃʃ/ =~ @onset.to_s))
    return "Vowel diacritics cannot have more than one character" if
        @v_diacritic.length > 3
    return "Tones cannot have more than one character" if @tone.length > 3
    return "Vowels cannot have more than two characters" if @vowel.length > 6
    return "Codas cannot have more than two consonants" if @coda.length > 6
    return "JPA Onsets cannot have more than two consonants" if @jonset.length > 2
    return "JPA Vowels cannot have more than one character" if @jvowel.length > 1
    return "JPA Vowel Lengths cannot have more than one character" if
        @jlength.length > 1
    return "JPA Codas cannot have more than two consonants" if @jcoda.length > 2
    return "JPA Tones cannot have more than one character" if
        @jtone.to_s.length > 1
end

# This class method checks an array of characters against a list of monosyllabic Thai
# words with irregular pronunciations. It returns true if the current array of characters
# matches one of these exceptions, false otherwise.
def Thai_syllable.exception?(arr)
    return true if /\u0e17\u0e40/ =~ arr[0..arr.length-1].to_s
    return true if /\u0e17\u0e41/ =~ arr[0..arr.length-1].to_s

```

```

return true if /\Aเร่ว\// =~ arr[0..arr.length-1].to_s
return true if /\Aเงิน\// =~ arr[0..arr.length-1].to_s
return true if /\Aจึง\// =~ arr[0..arr.length-1].to_s
return true if /\Aข้าง\// =~ arr[0..arr.length-1].to_s
return true if /\Aซ้ำ\// =~ arr[0..arr.length-1].to_s
return true if /\Aต้อง\// =~ arr[0..arr.length-1].to_s
return true if /\Aท่าน\// =~ arr[0..arr.length-1].to_s
return true if /\Aเพชร\// =~ arr[0..arr.length-1].to_s
return true if /\Aแฝด\// =~ arr[0..arr.length-1].to_s
return true if /\Aย่อง\// =~ arr[0..arr.length-1].to_s
return true if /\Aไว้\// =~ arr[0..arr.length-1].to_s
return true if /\Aแก้ว\// =~ arr[0..arr.length-1].to_s
return true if /\Aไล่\// =~ arr[0..arr.length-1].to_s
return true if /\Aเปล่า\// =~ arr[0..arr.length-1].to_s
return true if /\Aไม้\// =~ arr[0..arr.length-1].to_s
return true if /\Aหว่า\// =~ arr[0..arr.length-1].to_s
return true if /\Aเขา\// =~ arr[0..arr.length-1].to_s
return true if /\Aذن\// =~ arr[0..arr.length-1].to_s
return true if /\Aไหม\// =~ arr[0..arr.length-1].to_s
return true if /\Aเงิน\// =~ arr[0..arr.length-1].to_s
return true if /\Aจึง\// =~ arr[0..arr.length-1].to_s
return true if /\Aๆ\// =~ arr[0..arr.length-1].to_s
return true if /\Aฤ\// =~ arr[0..arr.length-1].to_s
return true if /\Aล้า\// =~ arr[0..arr.length-1].to_s
return true if /\Aซ้ำ\// =~ arr[0..arr.length-1].to_s
return true if /\Aซ้ำ\// =~ arr[0..arr.length-1].to_s
return true if /\An้ำ\// =~ arr[0..arr.length-1].to_s
return true if /\Aล้า\// =~ arr[0..arr.length-1].to_s
return false

```

end

This instance method takes a string of Thai characters (presumably a monosyllabic
 # word with exceptional pronunciation) and changes the irregular aspect of that word by
 # altering the instance variable(s) that involve the irregularity

```

def alter_word(thai_word)
  @jlength = ":" if thai_word == "แก้ว"
  @jlength = ":" if thai_word == "เหว"
  @jlength = ":" if thai_word == "เร่ว"
  @jlength = "." if thai_word == "เงิน"
  @jlength = "." if thai_word == "จึง"
  @jlength = "." if thai_word == "ข้าง"
  @jlength = "." if thai_word == "ซ้ำ"
  @jlength = "." if thai_word == "ต้อง"
  @jlength = "." if thai_word == "ท่าน"
  @jlength = "." if thai_word == "เพชร"
  @jlength = "." if thai_word == "แฝด"

```

```

@jlength = "." if thai_word == "ย่อง"
@jlength = "." if thai_word == "เฝ้า"
@jlength = ":" if thai_word == "เฝ้า"
@jlength = ":" if thai_word == "ไฉ่"
@jlength = ":" if thai_word == "เปล้า"
@jlength = ":" if thai_word == "ไฉ่"
@jlength = ":" if thai_word == "เหว"
@jtone = 3 if thai_word == "เขา"
@jtone = 3 if thai_word == "ฉัน"
@jtone = 3 if thai_word == "ไหม"
@jlength = "." if thai_word == "เงิน"
@jlength = "." if thai_word == "แจ้ง"
@jvowel = "y" if thai_word == "ฤ"
@jlength = ":" if thai_word == "ฤ"
@jlength = ":" if thai_word == "ฤก"
@jlength = "." if thai_word == "ร้า"
@jlength = "." if thai_word == "ร้า"
@jlength = "." if thai_word == "ร้า"
@jlength = "." if thai_word == "ร้า"
@jlength = "." if thai_word == "ร้า"
end

# This class method takes as input a string (presumably containing Thai script), parses it
# into syllables, and returns an array of Thai_syllable objects, one per parsed syllable.
def Thai_syllable.parse_string(instr_p)
  # To handle unicode properly in ruby v. 1.8, break the input string into individual
  # characters. Each element of the array _instr_ contains a string with only one
  # character.
  # The #scan method handles unicode b/c of the require 'jcode' at the top.
  instr = []
  # Add each character as a separate element of _instr_.
  instr_p.scan(/./){|c| instr << c}
  # Delete all unpronounced characters and all  characters (which mark characters
  # as silent) from the array
  if /\ =~ instr[0..instr.length-1].to_s then
    k = 0
    while k < instr.length do
      if instr[k] == "" then
        instr.delete_at(k)
        # If the silent marker follows a diacritic then delete
        # the preceding diacritic and the consonant it is
        # modifying
        if /\#{D}/\ =~ instr[k-1].to_s then
          instr.delete_at(k-1)
          instr.delete_at(k-2)
        else

```

```

                                # Otherwise, just delete the preceding consonant
                                instr.delete_at(k-1)
                                end
                            end
                        end
                        k += 1
                    end
                end
            end

# Delete all characters that are at the start of a sequence that precedes the
# abbreviation symbol "๑"; loop through all preceding characters, deleting one each
# time
if /๑/ =~ instr[0..instr.length-1].to_s then
    k = 0
    while k < instr.length do
        if /\A(\#{P}|\#{C}|\#{T}|\#{D}|\#{V})\)*๑/ =~ instr[k..instr.length-1].to_s then
            instr.delete_at(k)
        else
            k += 1
        end
    end
end

# Delete all Thai characters following the abbreviation symbol "๑"
k = 0
while k < instr.length do
    if /๑(\#{P}|\#{C}|\#{T}|\#{D}|\#{V})/ =~ instr[k-1..k].to_s then
        instr.delete_at(k)
    end
    k += 1
end

end

# Iterate through the array of characters, constructing syllables along the way.
# Whenever a syllable is complete, add it to the array _syllable_list_ and
# start a new syllable.
syllable_list = []
i = 0          # index into the array of input characters (_instr_).
b = 0          # aids in handling of certain exceptions (see v_prefix? if-block)
while i < instr.length do
    # Skip lines with "/" double slashes or backslashes at the end.
    break if /\A(.)*\\$/ =~ instr[i..instr.length-1].to_s
    break if /\A(.)*\\\\$/ =~ instr[i..instr.length-1].to_s
    # Skip lines with "." in them. These are abbreviations
    break if /\A(.)*\./ =~ instr[i..instr.length-1].to_s
    # Skip the rest of the line when a slash "/" or "%" or "#" is found. These
    # are titles or tags (not part of the corpus)

```

```

break if instr[i] =~ /\//
break if instr[i] == "#"
break if instr[i] =~ /%/
# _start_i_ is the index where construction of the current syllable begins.
# This is used to detect if the current character does not fit, so it can be
# skipped.
start_i = i
# Create a new syllable for parsing (the current syllable)
cur_syl = Thai_syllable.new
# Create a new syllable representing the previous syllable (to aid in tone
# translation)
prev_syl = Thai_syllable.new
if syllable_list.length > 0 then
  prev_syl = syllable_list[syllable_list.length-1]
end

# If the current character is the second member of a cluster handled by the
# exceptional case below (b = 1), then add the suppressed vowel prefix.
if b == 1 && instr[i-2] == "l" then
  cur_syl.add_v_prefix(instr[i-2])
  b = 0
end

# If the first character is a vocalic prefix character, add it as such.
if v_prefix?(instr[i]) then
# This handles an exception where vowels that have both a prefix preceding
# a consonant AND a 2nd vowel character following that consonant would
# be split into two vowels in rare cases when an onset cluster contains a
# sonorant C1 or an obstruent C2; the C1 is parsed in a separate syllable
# with an epenthetic a vowel; if this is the case, do not parse the prefix; set b
# to 1 so that the following iteration of the while loop (C2) will insert the
# vowel prefix (via the if block above)
  unless
    (/\A((#{C}#{C})((#{T}?[ᵿ])(#{T}?ᵿ)(#{T}?[ᵿ]))/ =~
    instr[i..i+5].to_s) && (not cluster?(instr,i+2)) then
    cur_syl.add_v_prefix(instr[i]); i += 1
  else
    # "b" = 1 marks the fact that we have one of these exceptions
    b = 1
  end
end

end

if must_be_onset?(instr,i) || (consonant?(instr[i]) && (not
must_be_vowel?(instr,i)) && (not must_be_coda?(instr,i)) && (not
cannot_be_onset?(instr,i))) then
  cur_syl.add_onset(instr[i])

```

```

        cur_syl.add_jonset(cur_syl.to_jpa_onset(instr[i])); i += 1
# If the character is a consonant that forms a licit cluster along with the
# preceding consonant AND either must be an onset or doesn't have to be a
# coda or vowel, add it to the onset
        if cluster?(instr,i) && (must_be_onset?(instr,i) ||
            (consonant?(instr[i]) && (not must_be_vowel?(instr,i)) && (not
                must_be_coda?(instr,i)) && (not cannot_be_onset?(instr,i))))
            then
                cur_syl.add_onset(instr[i])
                cur_syl.add_jonset(cur_syl.to_jpa_onset(instr[i]))
                # Call "silent_c" in order to map the written onset to the
                # pronounced onset
                cur_syl.alter_jonset(cur_syl.silent_c); i += 1
            end
        end

# If the onset is still empty, this is because the previous syllable required a
# coda and a single consonant character is acting simultaneously as onset &
# coda; the Thai writing system writes a consonant only once in this case; if
# the current syllable has no onset, add the coda of a previous syllable to the
# onset of the current one
        if (cur_syl.onset == "") && (i > 0) then
            cur_syl.add_onset(prev_syl.coda)
            cur_syl.add_jonset(cur_syl.to_jpa_onset(prev_syl.coda))
            cur_syl.add_ipa_onset(jpa_to_ipa(cur_syl.to_jpa_onset(instr[i])))
        end

# If the current character is a vowel diacritic character, add it as such.
        if v_diacritic?(instr[i]) then
            cur_syl.add_v_diacritic(instr[i]); i += 1
        end

# If the current character is a tone, add it as such.
        if tone?(instr[i]) then
            cur_syl.add_tone(instr[i]); i += 1
        end

# If the character is a possible vowel and it's not necessarily a coda or onset
# then parse it as a vowel.
        if must_be_vowel?(instr,i) || (vowel?(instr[i]) && (not
            must_be_coda?(instr,i)) && (not must_be_onset?(instr,i)) && (not
            cannot_be_vowel?(instr,i))) then
            cur_syl.add_vowel(instr[i]); i += 1
# Repeat once more since there can be two consecutive vowel characters (at
# most). This time strengthen the "or" to an "and" condition though.

```

```

        if must_be_vowel?(instr,i) && vowel?(instr[i]) && (not
            must_be_coda?(instr,i)) && (not must_be_onset?(instr,i)) &&
            (not cannot_be_vowel?(instr,i)) then
            cur_syl.add_vowel(instr[i]); i += 1
        end
    end

    # If the current character must be a coda or it's in a syllable that must be
    # closed OR it's a consonant that isn't necessarily a vowel or onset and it's
    # not that case that it can't be a coda or that the syllable must be open, then
    # parse it as a coda.
    if must_be_coda?(instr,i) || (cur_syl.must_be_closed? && (not
        cannot_be_coda?(instr,i))) || (consonant?(instr[i]) && (not
        must_be_vowel?(instr,i)) && (not must_be_onset?(instr,i)) && (not
        cannot_be_coda?(instr,i)) && (not cur_syl.must_be_open?)) then
        cur_syl.add_coda(instr[i])
        i += 1
        # A following consonant is parsed as a coda if the previous
        # conditions are met with the added necessity that the previous
        # consonant be "ɹ". Note the "or" conditions were strengthened to
        # "and" conditions.
        if must_be_coda?(instr,i) && consonant?(instr[i]) && (not
            must_be_vowel?(instr,i)) && (not must_be_onset?(instr,i)) &&
            (not cannot_be_coda?(instr,i)) && (/ɹ/ =~ instr[[0,i-1].max]) &&
            (not instr[i] == "ə") then
            cur_syl.add_coda(instr[i])
            i += 1
        end
        # [ɹi] sequences are not pronounced with an [i] vowel, as the
        # orthography implies; instead it is pronounced as [tɹ]; parse the ɹ as
        # a complex coda then.
        if /#{T}?ɹ\Z/ =~ instr[[0,i-3].max..i].to_s then
            cur_syl.add_coda(instr[i])
            i += 1
        end
    end

    # Translate the syllable into JPA (the onset has already been translated)
    cur_syl.add_jcoda(cur_syl.to_jpa_coda)
    cur_syl.add_jvowel(cur_syl.to_jpa_vowel)
    # Tone is determined by the "preceding" syllable in cases where an
    # epenthetic [a] breaks up an onset cluster. "tdc" is a variable that receives
    # the tone-determining consonant
    tdc = cur_syl.onset.to_s
    if syllable_list.length > 0 then
        # If the preceding syllable is epenthetic or if the vowel in the previous

```

```

# syllable is ɿ, AND the current syllable has a sonorant onset, set tdc to the
# first character in the preceding syllable's onset
    if ((prev_syl.epsyll?) || (prev_syl.vowel == "ɿ")) && (!A#{S}/ =~
        cur_syl.onset.to_s) then
        tdc = prev_syl.onset.to_s
    else
# Otherwise, set tdc to the first character in the current syllable's onset
        tdc = cur_syl.onset.to_s
    end
end
# Set the JPA length & tone, given the current syllable and tdc
cur_syl.add_jlength(cur_syl.to_jpa_length(tdc))
cur_syl.add_jtone(cur_syl.to_jpa_tone(tdc))

# If the current syllable is one of the listed monosyllabic exceptions,
# alter it accordingly
if exception?(instr) then
    cur_syl.alter_word(cur_syl.to_ts)
end

# Translate the syllable into IPA

cur_syl.add_ipa_onset(jpa_to_ipa(cur_syl.jonset[0,1]))
if cur_syl.jonset[1,1] != "" then
    cur_syl.add_ipa_onset(jpa_to_ipa(cur_syl.jonset[1,1]))
end
cur_syl.add_ipa_vowel(jpa_to_ipa(cur_syl.jvowel))
cur_syl.add_ipa_tone(jpa_to_ipa(cur_syl.jtone))
cur_syl.add_ipa_length(jpa_to_ipa(cur_syl.jlength))
cur_syl.add_ipa_coda(jpa_to_ipa(cur_syl.jcoda))

# The current character is still the initial one for this syllable, then it
# was not able to be included in a syllable. Skip to the next character,
# and start syllable parsing over. Otherwise, consider the constructed
# syllable complete: add it to the list.
if start_i == i then
    i += 1
else
    syllable_list << cur_syl
end
end # end of main while loop

return syllable_list
end
end

```



```

# The above code defined the Thai_syllable class, without actually executing
# anything. The actual execution happens below.

input_filename = "edited_orchid_corpus.txt"
# Check that a file with that name actually exists.
# If not, print an error message, and exit the program.
unless File.file? input_filename
  puts "File does not exist with name '#{input_filename}'"
  exit
end

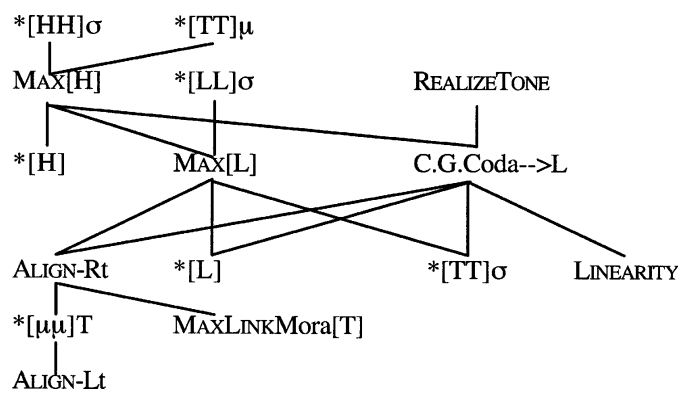
# Read the input file into an array of strings, one string per line.
lines = open(input_filename) {|f| f.readlines }
lines.each {|l| l.chomp!} # Remove the end-of-line marker from each string

# For each line of the input:
# * parse it into Thai syllables.
# * Write each syllable to a separate line of the output file.
# * Leave a blank line after the syllables for each input line.
output_filename = "output.txt"
open(output_filename, 'w') do |f|
  lines.each do |l|
    syls = Thai_syllable.parse_string(l)
    # Method #to_ts writes a syl. in Thai script.
    # Method #to_ts_verbose separately writes each syllable part.
    # Method #to_jpa writes a syl. in JPA script.
    # Method #to_jpa_verbose separately writes each JPA syllable part.
    # Method #check_syll includes error messages that warn us that the
    # syllable is deficient in some way
    syls.each{|s| f << s.to_ts << " " << s.to_ts_verbose << "\n " << s.to_ipa
      << " " << s.to_jpa << " " << s.to_jpa_verbose << "
      " << s.check_syll << "\n"}
    syls.each{|s| f << s.to_ts}
    f << "\n" # extra blank output line after the input line is complete.
  end
end
end

```

Appendix C

Morén & Zsiga's (2006:152) Final Constraint Ranking for Coda-Tone Interaction



Appendix D

Input-Output Mapping Assumed for Thai

The mapping shown here is based on the one assumed by Morén & Zsiga (2006).

Legend:

t: [+CG, –voice] onset consonant

d: [+CG, +voice] onset consonant

t^h: [–CG] onset consonant

T: [+CG] coda consonant

* The vowel [a] is used as an arbitrary choice, marked as short or long

* The Tonal short-hand notation used (i.e. HH) is summarized in Section 5.2.2.

		Input	Output
CVV	1	ta:HH	ta:HL
	2	ta:HM	ta:HL
	3	ta:HL	ta:HL
	4	ta:H2	ta:HL
	5	ta:MH	ta:HL
	6	ta:MM	ta:MM
	7	ta:ML	ta:ML
	8	ta:LH	ta:HL
	9	ta:LM	ta:ML
	10	ta:LL	ta:ML
	11	ta:L2	ta:ML
	12	t ^h a:HH	t ^h a:MH
	13	t ^h a:HM	t ^h a:MH
	14	t ^h a:HL	t ^h a:HL
	15	t ^h a:H2	t ^h a:MH
	16	t ^h a:MH	t ^h a:MH
	17	t ^h a:MM	t ^h a:MM
	18	t ^h a:ML	t ^h a:ML
	19	t ^h a:LH	t ^h a:LH
	20	t ^h a:LM	t ^h a:ML
	21	t ^h a:LL	t ^h a:ML
	22	t ^h a:L2	t ^h a:ML
	23	da:HH	da:HL
	24	da:HM	da:HL
	25	da:HL	da:HL
	26	da:H2	da:HL
	27	da:MH	da:HL
	28	da:MM	da:MM
	29	da:ML	da:ML

	30	da:LH	da:HL
	31	da:LM	da:ML
	32	da:LL	da:ML
	33	da:L2	da:ML
CVVT	34	ta:HHT	ta:MLT
	35	ta:HMT	ta:MLT
	36	ta:HLT	ta:MLT
	37	ta:H2T	ta:MLT
	38	ta:MHT	ta:MLT
	39	ta:MMT	ta:MLT
	40	ta:MLT	ta:MLT
	41	ta:LHT	ta:MLT
	42	ta:LMT	ta:MLT
	43	ta:LLT	ta:MLT
	44	ta:L2T	ta:MLT
	45	t ^h a:HHT	t ^h a:HLT
	46	t ^h a:HMT	t ^h a:HLT
	47	t ^h a:HLT	t ^h a:HLT
	48	t ^h a:H2T	t ^h a:HLT
	49	t ^h a:MHT	t ^h a:HLT
	50	t ^h a:MMT	t ^h a:MLT
	51	t ^h a:MLT	t ^h a:MLT
	52	t ^h a:LHT	t ^h a:HLT
	53	t ^h a:LMT	t ^h a:MLT
	54	t ^h a:LLT	t ^h a:MLT
	55	t ^h a:L2T	t ^h a:MLT
	56	da:HHT	da:MLT
	57	da:HMT	da:MLT
	58	da:HLT	da:MLT
	59	da:H2T	da:MLT
	60	da:MHT	da:MLT
	61	da:MMT	da:MLT
	62	da:MLT	da:MLT
	63	da:LHT	da:MLT
	64	da:LMT	da:MLT
	65	da:LLT	da:MLT
	66	da:L2T	da:MLT
CVT	67	taHHT	taL2T
	68	taHMT	taL2T
	69	taHLT	taL2T
	70	taH2T	taL2T
	71	taMHT	taL2T
	72	taMMT	taL2T
	73	taMLT	taL2T
	74	taLHT	taL2T

	75	taLMT	taL2T
	76	taLLT	taL2T
	77	taL2T	taL2T
	78	t ^{ha} HHT	t ^{ha} H2T
	79	t ^{ha} HMT	t ^{ha} H2T
	80	t ^{ha} HLT	t ^{ha} H2T
	81	t ^{ha} H2T	t ^{ha} H2T
	82	t ^{ha} MHT	t ^{ha} H2T
	83	t ^{ha} MMT	t ^{ha} L2T
	84	t ^{ha} MLT	t ^{ha} L2T
	85	t ^{ha} LHT	t ^{ha} H2T
	86	t ^{ha} LMT	t ^{ha} L2T
	87	t ^{ha} LLT	t ^{ha} L2T
	88	t ^{ha} L2T	t ^{ha} L2T
	89	daHHT	daL2T
	90	daHMT	daL2T
	91	daHLT	daL2T
	92	daH2T	daL2T
	93	daMHT	daL2T
	94	daMMT	daL2T
	95	daMLT	daL2T
	96	daLHT	daL2T
	97	daLMT	daL2T
	98	daLLT	daL2T
	99	daL2T	daL2T

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