Oral stop consonants in Tai Khamti: an acoustic study in voice onset time

©Douglas Inglis 2013 University of Alberta Prepublication draft—suggestions welcome
(Paper presented at ICSTLL46 Dartmouth College)

Introduction

The purpose of this study is to begin to phonetically document the minority language, Tai Khamti. There are no phonetic descriptions to date for Tai Khamti, and most of the phonetic studies of the Tai-Kadai language family pertain to tone (Edmonson and Solnit 1997). There are a few phonetic instrumental descriptions for Tai but most of these are limited to Thai (Edmonson et al. 2004; Harris 2001; Harris 1972; Harris and Noss 1972). This study is an instrumental description of the oral stops, both initial and medial, in manner of articulation. Based on the descriptive phonological studies of the Khamti language and on the orthography there are no distinct voiced oral stops (Wiedert 1977; Inglis 2006:25). Khamti then contributes typologically to the few languages within the Tai-Kadai family that have only a two-way distinction in oral stops. Most of the languages in this family, following Standard Thai, have a three-way distinction, voiced, voiceless aspirated and voiceless unaspirated (Lisker and Abramson 1964:389). This study seeks to verify this two-way oral stop analysis for Khamti with an acoustic measurement of voice onset time, which has been used to distinguish voiced, voiceless aspirated and voiceless unaspirated manners of articulation (Lisker and Abramson 1964; McDonough and Wood 2008:432-33; Cho and Ladefoged 1999; Keating 1984:290; Lisker et al. 1977).

For Khamti with its purported two-way oral stop distinction of aspirated-unaspirated, the hypothesis is that descriptively there are no voiced oral series of stops and statistically that there is a significant acoustic distinction between voiceless aspirated and voiceless unaspirated stops in both initial and sentence medial position. Secondary hypotheses are that there is a significant voice onset time distinction between labial, alveolar and velar points of articulation and between male and female speakers. All of these hypotheses arise from cross-linguistic typology (Lisker and Abramson 1964; Cho and Ladefoged 1999). The acoustic distinction for voicing and aspiration is measured in voice onset time and shows a significant difference exists, and this difference exists whether the stop is in a utterance initial or utterance medial position.

Language documentation work of a given language should include its phonetic description, barring a lack of access to speakers or good recordings in the case of severely endangered languages (Bhaskararao 2004). To this claim of the need to phonetically describe languages Ladefoged further motivates a description of voice onset time specifically. "Languages also differ in voice onset time (VOT), the interval between the release of a consonant (usually a stop) and the start of the voicing for the following vowel. Any description of the phonetic structures of a language should include an account of the VOT." (Ladefoged 2003:94)

Characteristics of the Tai language family include obligatory syllabic tone (a tone with each syllable of the morpheme) with 4 to 9 distinct level and/or contour tones, and isolating morphology in multi-syllabic compound words. For Tai Khamti there are five distinct tones. The consonant inventory of phones is, p, t, k, p^h, t^h, k^h, ʔ, h, ts, s, m, n, n^j, ŋ, l, r, w, y. This study in voice onset time is exclusive to the six oral stops, p, t, k, p^h, t^h, k^h.

Methods

Participants

Two participants were chosen as language consultants. Each of them are fluent mother-tongue speakers of Tai Khamti who were born and raised in villages from the heartland of the language group located in the northern most town, Putao, of Myanamar. This village and region is considered the major dialect area of Khamti. All other dialect areas have historically spread out from this region. The first participant is male, 46 years old and is a respected leader among his people in this region. The second participant is female, 21 years old, who grew up in a prominent and respected village of this region.

Data collection

The recordings were made in a closed room of a house in the capital city of Rangoon in July of 2005 on a Sony TCD-D3 DAT with a sampling rate of 22,000 Hz for an uncompressed digital output. These recordings were then transfered in real time to wav files on the computer. The recordings were of three types, isolated word lists, language lessons which included isolated words, which were then subsequently placed in simple contextual sentences, and finally, free-lance stories that each participant recounted from personal experience. In this way these words and sentences were constructed with the fluency and naturalness of normal converstation. These recordings were analyzed using Praat (Boersma and Weenink 2011).

Procedure

The procedure employed a spectrographic analysis of these tape recordings. Each language consultant produced sets of isolated words and sentences that used these words in context. Each of these recordings were segmented in Praat for specific words that were selected to include a sampling of all the initial oral stops found in Tai Khamti. From the segmented words I extracted all the measurements for voice onset time of the oral stops of these words, first in isolated word initial position. This procedure was then repeated targeting the same set of oral stops but in medial position of words and sentences. My definition of a medial environment is where oral stops are found either in a non-initial syllable of a word or in the initial syllable of a word but not the first word of a sentence. The total number of tokens collected for male and female are shown in Table 1.

	/p/	/p^h/	/t/	/t^h/	/k/	/k^h/
male	28	15	5	17	31	32
female	20	19	24	12	22	24
total	48	34	29	29	53	56

Table 1. Voice onset time in milliseconds: Tai Khamti (2 speakers)

Wide-band spectrograms of the recordings were made in Praat from these segmented words and from these words the voice onset time was measured by annotating the interval between the release of the oral stop (or the stop burst) and the onset of glottal vibration. I extracted the voice onset time measurement for each token of the oral stop. The voice onset time interval was measured from the stop burst to the onset of voicing. Oral closure is marked in the spectrogram by the near complete absence of acoustic energy in the formant frequency range and in no registration on the waveform. Oral release is marked by the abrupt onset of energy in the formant frequency. The stop burst occurs as a disruption in the steady flat reading within the oral closure where there is no voicing signaled in the waveform (Ladefoged 2003:96). It is also signaled spectrographically by an abrupt change in intensity amidst an almost total absence of acoustic energy in the formant frequency range (Lisker and Abramson 1964:389). In cases where there were several potential stop bursts detected, such as in a double burst common to velar releases, I consistently used the very intial burst. Following Lisker and Abramson (1964:389), the point of voicing onset was determined by locating the first of the regularly spaced vertical striations which indicate glottal pulsing. I marked the point on the waveform consistently after the first full cycle of this regular pattern of glottal pulsing at the zero point. I defined this point as the onset of voicing of the subsequent vowel. In measuring voice onset time the zero point of reference measurement is the occurrence of the burst to the zero point of the completion of the first cycle of a regular glottal pulse pattern. Any measurements of voicing that are recorded prior to the burst are recorded as negative numbers and called voicing lead. This measurement marks a voiced stop. Measurements of voicing that occur after the burst are recorded as positive numbers and called voicing lag. Both voiceless aspirated and voiceless unaspirated stops are distinguished in the measurement of voicing lag. Each measurement was rounded to the nearest millisecond (i.e. no fractional milliseconds). The measurements were then placed in a dataframe to be used for statistical analysis. The results of these measurements were then plotted in a boxplot to visualize potential significant differences in the means of voice onset time in relation to manner of articulation (aspiration), point of articulation (labial, alveolar and velar), position in the sentence (initial or medial) and gender (differences between male and female speakers). A Welch T-test was performed on the means to determine if the difference in the means of voice onset time was significant for any of the factors. The Welch t-test was chosen because it takes as assumptions that the distributions of comparison groups are somewhat normal but might have unequal variations. These assumptions were validated by inspection of the boxplots. The averaging, boxplotting and t-testing were done in R (R 2009; Baayen 2008:79). Finally, the mean of voice onset time over the tokens of each oral stop series, the range of values and the number of tokens were also recorded per oral stop. The resulting table was then aligned with the cross-linguistic study of oral stops from Lisker and Abramson (1964) and was compared with their results from other languages. Of special interest in the Lisker and Abramson study was their results for Thai oral stops. Tai Khamti is a Tai language related to Thai. Thai has a three-way manner series of oral stops with voiced, voiceless aspirated and voiceless unaspirated.

Results

The voice onset times were recorded and placed into a dataframe for further analysis. The first observational result was that there was no observable voicing lag time measurements. Next, the voice onset times were plotted to see if there was a difference in the aspirated, unaspirated times related to

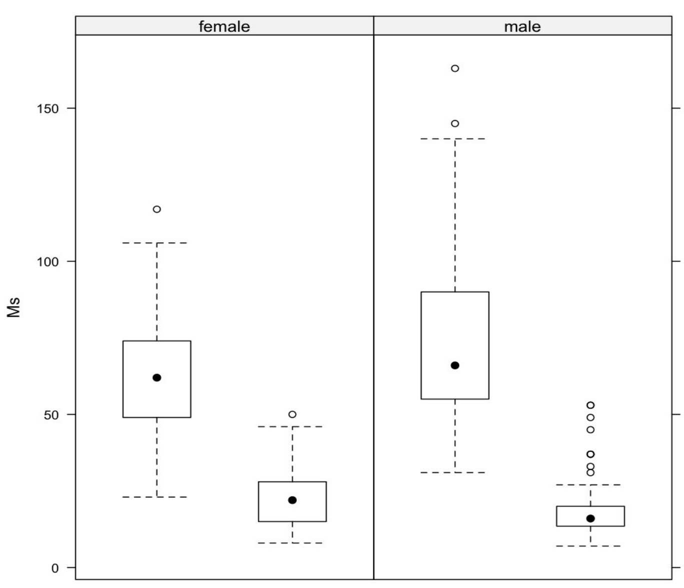

Figure 1. Voice onset time in aspiration differences across gender

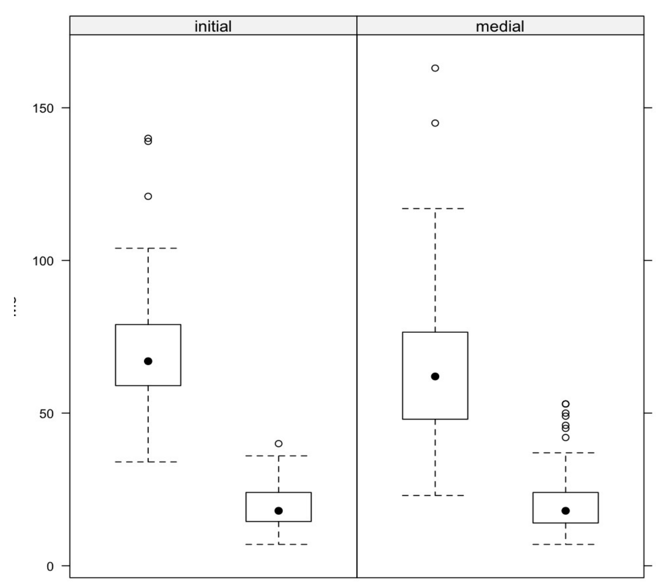

Figure 2. Voice onset time in aspiration differences across position

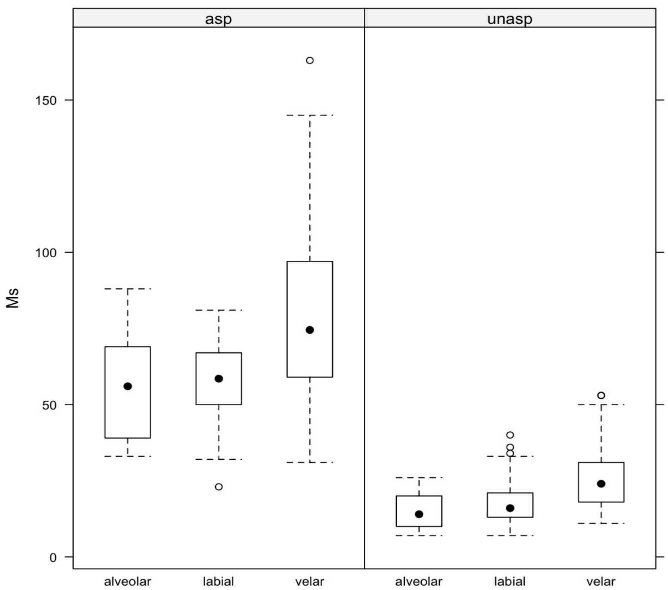

Figure 3. Voice onset time in point of articulation across aspiration

gender (male and female speakers), the oral stop position (occurring sentence initially or in a medial environment) and the point of articulation (labial, alveolar and velar). These boxplots are shown in Figures 1, 2 and 3 respectively. All three boxplots show a relatively normal distribution in all groups. This is shown by the consistent shape of each box relative to the median (the dot) which is somewhat centered. Each group also shows an unequal variation, indicated with the uneven whiskers on each box in comparison to different groups. These two assumptions, i.e., a somewhat normal distribution and unequal variations between groups, indicate that a Welch t-test would be the most appropriate in testing the significance of the means between two groups, as explained earlier. In all three boxplots there appears to be a significant difference in voice onset time betwen all aspirated and unaspirated stops. This can be seen in Figure 1 and 2 by the displacement of the aspirated boxes and their medians in relation to the aspirated boxes. In Figure 3 the three boxes in the left half of the figure show a strong displacement from the three boxes in the right half of the figure. This represents a significant difference in aspirated stops at each point of articulation with their unaspirated counterparts, respectively. Also, Figure 3 indicates that, in both aspirated and unaspirated stops, the velars appear to be the most distinct in voice onset time from both the labials and alveolars. The results from these boxplots warranted t-tests in order to see if the means of the aspirated and unaspirated stops were indeed significant, and if there was a significant difference between velars as opposed to labials and alveolars. I also tested to see if there was even a significant difference between points of articulation of all pairs. The test in Figure 4 shows that the mean of aspirated stops is 79.53 milliseconds and the mean of unaspirated stops is 27.26 milliseconds, and that the difference between these means is highly significant at p-<2.2e-16.

```
        Welch Two Sample t-test

t = 19.3917, df = 132.54, p-value < 2.2e-16
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 43.52097 53.40809
sample estimates:
mean of x   mean of y
 68.85185   20.38732
```

Figure 4. T-test for aspirated and unaspirated stops

The test in Figure 5 shows that the mean of the velar stop is 53.65 milliseconds and the mean of labial stops is 35.04 milliseconds, and that the difference between these means is highly significant at p=9.311e-06.

```
        Welch Two Sample t-test

t = 4.5585, df = 186.262, p-value = 9.311e-06
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 10.55882 26.67076
sample estimates:
mean of x   mean of y
 53.65138   35.03659
```

Figure 5. T-test for velar and labial points of articulation in stops

The test in Figure 6 shows that the mean of velar stop is 53.65 milliseconds and the mean of alveolar stops is 27.29 milliseconds, and that the difference between these means is highly significant at p=4.296e-09.

```
            Welch Two Sample t-test

t = 6.2079, df = 162.807, p-value = 4.296e-09
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 17.97743 34.74905
sample estimates:
mean of x mean of y
 53.65138  27.28814
```

Figure 6. T-test for velar and alveolar points of articulation in stops

The test in Figure 7 shows that the mean of velar stop is 35.04 milliseconds and the mean of alveolar stops is 27.29 milliseconds, and that the difference between these means is only somewhat significant at p=0.037, in comparison to the p-values of the velar.

```
            Welch Two Sample t-test

t = 2.0971, df = 129.637, p-value = 0.03793
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
  0.4384814 15.0584181
sample estimates:
mean of x    mean of y
 35.03659    27.28814
```

Figure 7. T-test for labial and alveolar points of articulation in stops

Discussion

The first point of discussion arises from the result of there being no lag time measurements observed in the data. This confirms the hypothesis (and phonological analyses and orthography) that Khamti does not have voiced oral stops. Khamti then falls within the two-way oral stop systems in Lisker and Abramson (1964). Furthermore, the boxplot in Figure 1 rougly indicates that there is actually not a significant difference between male and female speakers when it comes to the voice onset time between aspirated and unaspirated stops. Albeit, the sample derives from only one male and one female speaker so extrapolation to the general population is not really warranted. However, for this analysis the medians are pretty much equal between the male and female speaker so I did not make any further distinctions in this analysis between male and female and so combined their tokens for the subsequent tests. The boxplot in Figure 2 shows that there is also no significant difference whether the oral stop occurs sentence initially or medially. The medians across the two environments are almost the same. Therefore, I did not make any further distinctions in the analysis between initial and medial position and combined those tokens for subsequent tests. After I concluded that gender and position were not significant factors in this analysis I plotted voice onset time across the three points of articulation in relation to aspiration. The resulting boxplot in Figure 3 shows three potentially significant results. First, for male and female speakers in both initial and medial environments, there is an apparent significant distinction between the voice onset time and aspirated and unaspirated stops. Therefore I ran a t-test on this result to verify that a significance existed. The results of the t-test, shown in Figure 4, show that voice onset time is a very strong indicator for the distinction of aspirated and unaspirated stops in Khamti. The results of the remaining three t-tests (in Figures 5, 6, 7 respectively) show that voice onset time is a very strong indicator for the distinction of velar from labial points of articulation in Khamti. Voice onset time also is a very strong indicator for the distinction of velar from alveolar points of articulation in Khamti. Finally, voice onset time is somewhat of an indicator for the distinction of alveolar from labial points of articulation in Khamti. I say somewhat of an indicator because the significance test, while still showing significance, was quite a bit less significant than the velar result. This is not surprising since it has been observed cross-linguistically that velar point of articulation is very distinct from both alveolar and labial in voice onset time.

Conclusion

In conclusion each of the hypotheses for this paper have been tested using spectrographic analysis of voice onset time. The hypothesis that descriptively there are no voiced oral series of stops is confirmed by the lack of any observable data with lead time measurement of voicing. While acknowleding the overall low token count, a statistical significant acoustic distinction does exist between voiceless aspirated and voiceless unaspirated stops in both initial and sentence medial position. Furthermore, there is a significant voice onset time distinction between labial, alveolar and velar points of articulation. However, the hypothesis that there is a significant voice onset time distinction between male and female speakers was not confirmed. Finally, in relating this study of Tai Khamti back to Lisker and Abramson (1964), I offer Table 2 for easy cross-referencing to their study. In their paper Av. means average in milliseconds, R. means range in milliseconds and N. means number of tokens.

	/p/	/p^h/	/t/	/t^h/	/k/	/k^h/
Av.	18	59	15	55	26	80
R.	7:40	23:81	7:25	33:88	11:53	42:163
N.	34	58	65	18	53	56

Table 2. Voice onset time in milliseconds: Tai Khamti (2 speakers)

In comparing the result in Table 2 with the results from Lisker and Abramson for languages with two-way contrast Tai Khamti there is only one language, Cantonese, that show a two-way contrast in stops with voiceless asprated and unaspirated manner of articulation. The other two-way contrasts employ a voice series of contrast.

	/p/	/p^h/	/t/	/t^h/	/k/	/k^h/
Av.	9	77	14	75	34	87
R.	0:20	35:110	5:25	45:95	22:55	70:115
N.	15	15	12	15	15	15

Table 3. Voice onset time: Cantonese (1 speaker),
from Lisker and Abramson (1964:394)

Comparing Tai Khamti, Table 2, with Cantonese, Table 3, there is a difference in token counts, with Khamti having at least twice the count but also using 2 speakers instead of one. The average distinction in voice onset time between aspirated and unaspirated labial and alveolar is much greater in Cantonese, but with the velars there is not much difference between the two languages. Table 4 shows the results from Lisker and Abramson for Thai, which is closely related to Khamti. However, Thai also includes a set of voiced stops for labial and alveolar (there is no /g/ in Thai).

	/p/	/pʰ/	/t/	/tʰ/	/k/	/kʰ/
Av.	6	64	9	65	25	100
R.	0:20	25:100	0:25	25:125	0:40	50:155
N.	32	33	33	33	32	38

Table 4. Voice onset time: Thai (3 speakers), adapted from Lisker and Abramson (1964:396)

It is interesting to note that the averages between Khamti and Thai are very similar despite the fact that Thai also has a voiced series. From a typological perspective, then, the results of this study in Khamti fit comfortably with the data from Cantonese and Thai for voice onset time in oral stops.

Appendix A. Dataframe voice onset time Tai Khamti

Poa	Manner	Position	Gender	Ms
labial	unasp	initial	male	12
labial	unasp	initial	male	10
labial	unasp	initial	male	7
labial	unasp	initial	male	16
labial	unasp	initial	male	16
labial	unasp	initial	male	11
labial	unasp	initial	male	16
labial	unasp	initial	male	15
labial	unasp	initial	male	15
labial	unasp	initial	male	20
labial	unasp	initial	male	16
labial	unasp	initial	male	14
labial	unasp	initial	male	19
labial	unasp	initial	male	17
labial	unasp	initial	male	16
labial	unasp	initial	male	24
labial	asp	initial	male	57
labial	asp	initial	male	50
labial	asp	initial	male	62
labial	asp	initial	male	64
labial	asp	initial	male	55
labial	asp	initial	male	63
labial	asp	initial	male	61
labial	asp	initial	male	54
labial	asp	initial	male	73
labial	asp	initial	male	79
labial	unasp	medial	male	14
labial	unasp	medial	male	12
labial	unasp	medial	male	9
labial	unasp	medial	male	16
labial	unasp	medial	male	20
labial	unasp	medial	male	7
labial	unasp	medial	male	14
labial	unasp	medial	male	16

labial	unasp	medial	male	18
labial	unasp	medial	male	16
labial	unasp	medial	male	18
labial	unasp	medial	male	14
labial	asp	medial	male	79
labial	asp	medial	male	63
labial	asp	medial	male	43
labial	asp	medial	male	54
labial	asp	medial	male	43
alveolar	unasp	initial	male	19
alveolar	unasp	initial	male	14
alveolar	unasp	initial	male	10
alveolar	unasp	initial	male	18
alveolar	asp	initial	male	88
alveolar	asp	initial	male	55
alveolar	asp	initial	male	34
alveolar	asp	initial	male	76
velar	asp	initial	male	59
velar	asp	initial	male	66
velar	asp	initial	male	70
velar	asp	initial	male	91
velar	asp	initial	male	59
velar	asp	initial	male	47
velar	asp	initial	male	98
velar	asp	initial	male	101
velar	asp	initial	male	79
velar	asp	initial	male	104
velar	asp	initial	male	139
velar	asp	initial	male	121
velar	asp	initial	male	73
velar	asp	initial	male	140
velar	asp	initial	male	89
velar	unasp	initial	male	25
velar	unasp	initial	male	18
velar	unasp	initial	male	19
velar	unasp	initial	male	13
velar	unasp	initial	male	17
velar	unasp	initial	male	19

velar	unasp	initial	male	18
velar	unasp	initial	male	21
velar	unasp	initial	male	20
velar	unasp	initial	male	20
velar	unasp	initial	male	16
velar	unasp	initial	male	19
velar	unasp	medial	male	18
velar	unasp	medial	male	53
velar	unasp	medial	male	33
velar	unasp	medial	male	37
velar	unasp	medial	male	53
velar	unasp	medial	male	15
velar	unasp	medial	male	15
velar	unasp	medial	male	31
velar	unasp	medial	male	11
velar	unasp	medial	male	21
velar	unasp	medial	male	37
velar	unasp	medial	male	49
velar	unasp	medial	male	45
velar	unasp	medial	male	27
velar	unasp	medial	male	37
velar	unasp	medial	male	22
velar	unasp	medial	male	22
velar	unasp	medial	male	16
velar	unasp	medial	male	15
velar	asp	medial	male	58
velar	asp	medial	male	81
velar	asp	medial	male	66
velar	asp	medial	male	48
velar	asp	medial	male	51
velar	asp	medial	male	52
velar	asp	medial	male	97
velar	asp	medial	male	101
velar	asp	medial	male	63
velar	asp	medial	male	52
velar	asp	medial	male	100
velar	asp	medial	male	74
velar	asp	medial	male	92

velar	asp	medial	male	145
velar	asp	medial	male	56
velar	asp	medial	male	31
velar	asp	medial	male	163
alveolar	asp	medial	male	69
alveolar	unasp	medial	male	10
alveolar	unasp	medial	male	16
alveolar	unasp	medial	male	7
alveolar	unasp	medial	male	9
alveolar	unasp	medial	male	10
alveolar	unasp	medial	male	22
alveolar	unasp	medial	male	11
alveolar	unasp	medial	male	7
alveolar	unasp	medial	male	14
alveolar	unasp	medial	male	8
alveolar	unasp	medial	male	8
alveolar	unasp	medial	male	16
alveolar	unasp	medial	male	9
labial	unasp	initial	female	13
labial	unasp	initial	female	19
labial	unasp	initial	female	15
labial	unasp	initial	female	12
labial	unasp	initial	female	13
labial	unasp	initial	female	28
labial	unasp	initial	female	32
labial	unasp	initial	female	40
labial	unasp	initial	female	36
labial	unasp	initial	female	17
labial	unasp	initial	female	29
labial	unasp	initial	female	12
labial	unasp	initial	female	12
labial	asp	initial	female	62
labial	asp	initial	female	56
labial	asp	initial	female	71
labial	asp	initial	female	56
labial	asp	initial	female	59
labial	asp	initial	female	67
labial	asp	initial	female	78

labial	asp	initial	female	70
labial	asp	initial	female	50
labial	asp	medial	female	47
labial	asp	medial	female	81
labial	asp	medial	female	52
labial	asp	medial	female	47
labial	asp	medial	female	32
labial	asp	medial	female	23
labial	asp	medial	female	48
labial	asp	medial	female	73
labial	asp	medial	female	58
labial	asp	medial	female	62
labial	unasp	medial	female	29
labial	unasp	medial	female	33
labial	unasp	medial	female	22
labial	unasp	medial	female	22
labial	unasp	medial	female	13
labial	unasp	medial	female	32
labial	unasp	medial	female	34
alveolar	unasp	medial	female	12
alveolar	unasp	medial	female	14
alveolar	unasp	medial	female	9
alveolar	unasp	medial	female	20
alveolar	unasp	medial	female	24
alveolar	unasp	medial	female	12
alveolar	unasp	medial	female	18
alveolar	unasp	medial	female	11
alveolar	unasp	medial	female	22
alveolar	unasp	medial	female	18
alveolar	unasp	medial	female	15
alveolar	unasp	medial	female	18
alveolar	asp	medial	female	38
alveolar	asp	medial	female	33
alveolar	asp	medial	female	39
alveolar	asp	medial	female	44
alveolar	asp	medial	female	62
alveolar	asp	medial	female	48
alveolar	asp	medial	female	71

alveolar	asp	medial	female	57
alveolar	asp	medial	female	40
alveolar	asp	initial	female	65
alveolar	asp	initial	female	60
alveolar	asp	initial	female	72
alveolar	asp	initial	female	39
alveolar	unasp	initial	female	17
alveolar	unasp	initial	female	13
alveolar	unasp	initial	female	13
alveolar	unasp	initial	female	8
alveolar	unasp	initial	female	25
alveolar	unasp	initial	female	22
alveolar	unasp	initial	female	26
alveolar	unasp	initial	female	24
alveolar	unasp	initial	female	20
alveolar	unasp	initial	female	11
alveolar	unasp	initial	female	20
alveolar	unasp	initial	female	20
velar	unasp	initial	female	31
velar	unasp	initial	female	18
velar	unasp	initial	female	17
velar	unasp	initial	female	33
velar	unasp	initial	female	16
velar	unasp	initial	female	24
velar	unasp	initial	female	28
velar	unasp	initial	female	29
velar	unasp	initial	female	31
velar	unasp	initial	female	25
velar	unasp	initial	female	29
velar	asp	initial	female	67
velar	asp	initial	female	79
velar	asp	initial	female	42
velar	asp	initial	female	73
velar	asp	initial	female	75
velar	asp	initial	female	85
velar	asp	initial	female	100
velar	asp	initial	female	59
velar	asp	initial	female	78

velar	asp	initial	female	49
velar	asp	initial	female	60
velar	asp	initial	female	82
velar	asp	initial	female	80
velar	asp	initial	female	55
velar	asp	initial	female	82
velar	asp	medial	female	106
velar	asp	medial	female	71
velar	asp	medial	female	117
velar	asp	medial	female	67
velar	asp	medial	female	71
velar	asp	medial	female	49
velar	asp	medial	female	65
velar	asp	medial	female	79
velar	asp	medial	female	97
velar	unasp	medial	female	24
velar	unasp	medial	female	24
velar	unasp	medial	female	21
velar	unasp	medial	female	42
velar	unasp	medial	female	28
velar	unasp	medial	female	50
velar	unasp	medial	female	24
velar	unasp	medial	female	46
velar	unasp	medial	female	24
velar	unasp	medial	female	24
velar	unasp	medial	female	24

Bibliography

Bhaskararao, Peri. 2004. Phonetic documentation of endangered languages: Creating a knowledge-base containing sound recording, transcription and analysis. *Acoustical Science and Technology*. 25,4. 219-26.

Baayen, R. H. 2008. *Analyzing Linguistic Data: a Practical Introduction to Statistics Using R*. Cambridge University Press.

Boersma, Paul and David Weenink. 2011. Praat: doing phonetics by computer. Phonetic Sciences, University of Amsterdam. www.praat.org. Version 5.2.12

Cho, T., & Ladefoged, P. 1999. Variation and universals in VOT: evidence from 18 languages. *Journal of Phonetics. 27*(2), 207-229.

Denes, P. 1955. Effect of Duration on the perception of voicing. *The Journal of the Acoustical Society of America. 27*(4), 761-764.

Edmondson, Jerold A., Esling, John H., Harris, Jimmy G., & Wei, James. 2004. A phonetic study of Sui consonants and tones. Mon-Khmer Studies 34:47-66.

Edmondson, Jerold A., and David B. Solnit, eds. 1997. *Comparative Kadai: The Tai Branch*. Edited By D.A. Burquest. Vol 124, *SIL and UTA Publications in Linguistics*. Arlington, TX: SIL.

Feth, L. L., Fox, R. A., Jacewicz, E., & Iyer, N. 2006. Dynamic center-of-gravity effects in consonant-vowel transitions. *Dynamics of Speech Production and Perception.* 103.

Gordon, M., & Ladefoged, P. 2001. Phonation types: a cross-linguistic overview. *Journal of Phonetics. 29*(4), 383-406.

Haggard, M., Ambler, S., & Callow, M. 1970. Pitch as a voicing cue. *The Journal of the Acoustical Society of America. 47*(2B), 613-617.

Harris, Jimmy G. 2001. States of the glottis of Thai voiceless stops and affricates. In K. Tingsabadh and A. S. Abramson (eds.) *Essays in Tai Linguistics*. Bangkok: Chulalongkorn University Press. 3-11.

Harris, Jimmy G. 1976. Notes on Tai Khamti. In Thomas W. Gething Et al. eds., *Tai Linguistics in Honor of Fang-Kuei Li*. Chulalongkorn University Press: Bangkok.

Harris, Jimmy G. 1972. Phonetic notes on some Siamese consonants. In J. G. Harris and R. B. Noss (eds.) 8-22.

Harris, Jimmy G. and R. B. Noss (eds.). 1972. *Tai Phonetics and Phonology*. Central Institute of English Language: Bangkok.

Inglis, Douglas. 2007. Nominal structure of Tai Khamti. Linguistics Department, Payap University. *Technical Paper #203*

Keating, P. A. 1984. Phonetic and phonological representation of stop consonant voicing. *Language. 60*(2), 286-319.

Kuhl, P. K., & Miller, J. D. 1975. Speech perception by the chinchilla: voiced-voiceless distinction in alveolar plosive consonants. *Science. 190*(4209), 69.

Ladefoged, Peter. 2003. *Phonetic Data Analysis: an Introduction to Fieldwork and Instrumental Techniques*. Blackwell Publishing.

Laver, John. 1994. *Principles of Phonetics.* Cambridge University Press.

Lisker, L. and Abramson, A. S. 1964. A cross-language study of voicing in initial stops: acoustical measurements. *Word. 20*(3), 384-422.

Lisker, L., Liberman, A. M., Erickson, D. M., Dechovitz, D., & Mandler, R. 1977. On pushing the voice-onset-time (VOT) boundary about. *Language & Speech. 20*(3), 209-216.

McDonough, J., & Wood, V. 2008. The stop contrasts of the Athabaskan languages. *Journal of Phonetics. 36*(3), 427-449.

Ohala, J. J. 1997. Emergent stops. *Proc. 4th Seoul International Conference on Linguistics.* 11–15.

Ohala, J. J. 1990. There is no interface between phonology and phonetics: a personal view. *Journal of Phonetics. 18*, 153–171.

R version 2.10.0. Copyright (C) 2009. (2009-10-26) The R Foundation for Statistical Computing ISBN 3-900051-07-0.

Repp, B. H. 1979. Relative amplitude of aspiration noise as a voicing cue for syllable-initial stop consonants. *Language & Speech. 22*(2), 173-189.

Stevens, K. N., & Klatt, D. H. 1974. Role of formant transitions in the voiced-voiceless distinction for stops. *The Journal of the Acoustical Society of America. 55*(3), 653-659.

Wiedert, Alfons. 1977. *Tai Khamti Phonology and Vocabulary*. Wiesbaden: Franz Steiner Verlag.