# Acoustic Space, Duration and Formant Patterns in vowels of Bangkok Thai

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**Abstract**

*Acoustic space is a useful tool which shows how the formant frequencies help objectively define the vowel space in a language. The present study revalidates the use of an empirically verifiable, quantifiable concept of acoustic space which also helps us revisit the DT Hypothesis and Quantal Theory. Through this study the authors show how relative positioning of vowels in vowel space is more important and useful a marker for an individual speaker or a language or even a linguistic region than formant values of individual vowels. Since the data collected for the present study comes from a tone language, the authors also examine the correlations, if any, between spectral characteristics, duration and pitch/ phonemic tones in Thai language. Some interesting correlations emerge which need to be examined with data from more tonal languages, as well as non-tonal languages.*

**Keywords**

*Acoustic Space, Formants, Fundamental Tone as F0, Pitch and Tone.*

## 1 Introduction

Studies on Acoustic Space show how the formant frequencies help objectively define the vowel space in a language. Mapping of acoustic space is useful for the purpose of comparing languages and individual speakers. This is an empirical study based on the data collected from Thai speakers located in Bangkok to determine the acoustic space of the vowels of Bangkok Thai. Since Vowel Duration is also phonemic in Bangkok Thai, the present study proposes to find out the correlation, if any, between Vowel Duration and the spectral/formant characteristics of vowels in Thai language. Examining the spectral characteristics the authors also work on the hypothesis that pitch varies with the tongue height/ F1 while the third formant seems to roughly correlate with the second formant.

**Main Objectives of the present study are**

- *To examine the Acoustic Space of Vowels in Thai.*
- *To examine Durational Contrast and Centralization of Vowels in Thai.*

- *To Study F1 Correlation with F0 in a Tone Language i.e. Thai.*
- *To Study the Correlation of F3 with F2 and F1 in Thai.*

***Research Questions for the present study can be briefly summed up as:***

***Acoustic Space of Vowels in Thai***

- *Can we use acoustic space as a viable, practical measure to describe relative positions of vowels in vowel space in a specific language?*
- *What is the effect of pitch variations, especially when there are phonemic tones in a given language, on acoustic space?*
- *Thai has five tones (levels and contours); a good object to study if the effect of pitch levels & contours on acoustic space is different.*

***Durational Contrast and Centralization of Vowels in Thai***

- *What is the effect of durational variations, in vowels on acoustic space?*

***To Study F1 Correlation with F0 in a Tone Language- as in Thai***

- *What is the correlation between F1 and F0/ pitch?*
- *What is the effect of pitch variations, especially when they are phonemic tones in a given language, on F0 and F1 correlation?*

***To Study the Correlation of F3 with F2 and F1 in Thai***

- *How does F3 co-relate with the first and the second formant?*

## 2 Background Studies

### 2.1 Vowel Space in Acoustic terms

Catford (1988) talks about the concepts called "vowel space" and "vowel limit". He says that the idea of the Cardinal Vowels by the renowned phonetician Daniel Jones is based on the concept that the vowels are limited by vowel space/limit. In the production of a vowel, there is a certain fixed area/space within oral-pharyngeal cavity, beyond which the vowel takes space of an approximate type sound. Thus, theoretically speaking, "any vowel of any language must have its tongue-position either on the vowel limit itself, or within the Vowel Space " (Catford, 1988:130)

Dispersion theory (DT) claims that speech sounds are selected via constraints that are based on a principle of sufficient perceptual contrast. I n this theory the vowels of a given language are arranged in the acoustic vowel space so as to minimize the potential for perceptual confusion between the distinct vowel categories. Using computer programs to generate the optimal configurations for vowel systems of various sizes, this approach to vowel inventories has proved fairly successful (Liljencrants and Lindblom, 1972; Lindblom, 1975, 1986; Disner, 1984). According to the Quantal Theory of Speech (QTS), there are certain regions of stability in the phonetic space (Stevens, 1972, 1989).Studies on Acoustic Space show how the formant frequencies help objectively define the vowel space in a language. The present study on revalidates the use of an empirically verifiable, quantifiable concept of acoustic space which helps us revisit the DT Hypothesis and Quantal Theory.

**2.2 Duration and Spectral quality of vowels**

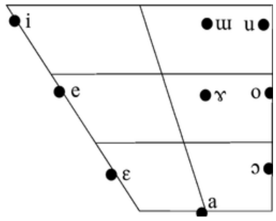
The durational contrast may or not may be the only distinctive feature between two vowels. e.g. Hindi short vowels /I/, /U/ and /ə/ are qualitatively distinct from their corresponding long vowels. According to Tsukada Kimiko (2009) Vowel duration is used contrastively in some languages, but not in others. In languages where it is used as an acoustic cue to the vowel identity, its dominance (prominence) as a primary cue appears to vary from one language to another. In languages such as Japanese (e.g. Vance 1987; Tsujimura 1996) and Thai (e.g. Abramson 1974; Gandour 1984; Abramson & Ren 1990; Abramson 2001), vowel length is phonemic and duration is the main acoustic cue to differentiate biru 'building' from biiru 'beer' in Japanese. In other languages such as English and German, /i/ and /I/ differ both in spectral quality and duration (e.g. Peterson & Lehiste 1960; House 1961; Bohn & Flege 1992; Hillenbrand et al. 1995). Thus, English and also Hindi would presumably differ from Japanese and Thai since both these languages use vowel duration as an acoustic cue for the length distinction in addition to qualitative differences to maintain the contrast between /i/ and /i:/, /u/ and /u:/, /a/ and /a:/ (For Hindi see Narang 2010, Mishra, 2009). In Japanese and Thai, length contrast is predominantly cued by durational differences whereas English uses other acoustic cues such as spectral differences (Tsukada Kimiko, 2009:127-138).

According to Roengpitya (1999), in standard Thai, vowel length is contrastive e.g. [cìp] 'to sip"- [cǐip] 'to pleat'. Historically speaking, Li (1977) reconstructed vowels in Proto- Tai without a length distinction. In standard Thai, Abramson (1962) said that vowel duration is the main cue to distinguish short and long vowels. Abramson and Ren (1990) found that the audible secondary cue for vowel length in Thai is vowel quality. The previous experiment of Roengpitya (1999) confirmed that other perceptual cues besides vowel duration could be vowel quality and final nasal duration. It is found that short vowels are more centralized than long vowels. Moreover, short vowels are followed by longer final nasals and long vowels are followed by shorter final nasals, as also found by Abramson (1962), by Onsuwan and Beddor (1989), and by Roengpitya (1999).

In a recent study on Japanese vowels, it was found that there is a significant effect of vowel length on vowel quality such that long vowels generally occupied a more peripheral portion of the vowel space than did the short vowels (Hirata & Tsukada). We sought to determine if the same pattern could also be observed in Thai.

**2.3 Vowels and Tonal phonemes in Thai**

According to Burapha, (2006) Thai comes from Tai-Kadai language family, belongs to isolated language type and has five tones (Burapha, 2006: 155). According to Tingsabadh & Abramson (1993) there are nine vowels with durational contrast making it a full inventory of eighteen vowels, as shown on the cardinal vowel chart below:

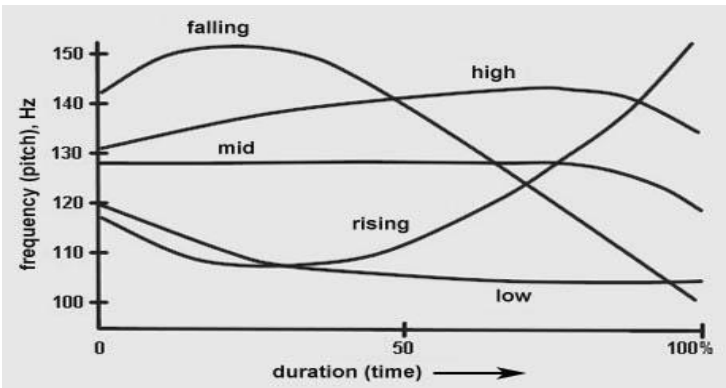



Monophthongs of Thai. From Tingsabadh & Abramson (1993:25)

According to Tingsabadh & Abramson 1993, the basic vowels of the Thai language are nine long vowels /i:, ɯ:, u:, e:, o:, ☜:, ❷:, a:, ɤ :/ and corresponding nine short vowels, /i, ɯ, u, e, o, ☜, ❷, a, ɤ /. These vowels exist in long-short pairs as distinct phonemes, some examples from Tingsabadh & Abramson (1993) to illustrate the contrast are: /fă:n/ 'to slice' /făn/ to dream', /sɯ̀t/ 'rear most' /sɯ̀:t/ 'to inhale' , /pʰɛ́ʔ/ 'goat' /pʰɛ́:/ 'to be defeated" , /kʰôn/ 'thick (soup)' /kʰô:n/ 'to fell', /klɔ̀ŋ/ 'box' /klɔ:ŋ/ 'drum'

**2.4 Tones in Thai**

According to Fromkin (1978) Thai, the national language of Thailand, exhibits five contrastive tones, traditionally labeled mid (¯), low (`), falling ( ^ ), high ( ´ ) and rising ( ˇ). The following set of words illustrates these tones: khaa ‘a grass, khàa ‘galangal, a fhizome’, khâa ‘to kill’, khăa to engage in trade’. Average fundamental frequency contours of the five Thai tones in prepausal position are presented in figure given below:




(Fromkin, 1978:43)

It has been shown that Thai listeners can easily identify the tones in real speech monosyllabic words, even in isolation from any phonetic or linguistic context (Fromkin 1978:43).

## 3 Methodology

The present study is focused on the formant characteristics of Bangkok Thai vowels and their duration. However keeping in mind the fact that it is a tonal language all the examples included in the present study were with level tone only.

### 3.1The Acoustic Parameters

The present study attempts to describe the vowels empirically using the following parameters.

i) Durational contrasts.
ii) Formants F1, F2, F3.
iii) Acoustic Space in terms of F1 and F2.

Pitch levels and contours in Bangkok Thai words selected for the purpose, was constant i.e. mid / level tone.

### 3.2 Subject Selection

Four male and four female speakers were selected randomly and out of the random sample we selected the best recording which was also adjudged by the native speakers of Thai as most clear articulation of words. The selected subject is female aged 46. This speaker's family belongs to central part of Thailand and the subject after completing her graduation lived in Bangkok for more than 25 years.

### 3.3 Elicitation of Data

Following words were selected which include all 18 vowels in the medial position-

| | | |
|---|---|---|
| **/i/** | /khȉt/ | cloth |
| **/i:/** | /khì:t/ | line |
| **/ɯ/** | /pl**ɯk/** | crystal |
| **/ɯ:/** | /pl**ɯ:k/** | itchy skin |
| **/u/** | /khùt/ | digging |
| **/u:/** | /khù:t/ | doing a crush |
| **/e/** | /khèt/ | be afraid |
| **/e:/** | /khè:t/ | border |
| **/ ɤ /** | /t̀ɤ / | thick |
| **/ ɤ:/** | /t̀ɤ̀:/ | too short |
| **/o/** | /sòk/ | year |
| **/o:/** | /sò:k/ | sadness |
| **/☜/** | /k☜/ | sheep |
| **/☜:/** | /k☜:/ | old people |
| **/❷/** | /k❷/ | island |
| **/❷:/** | /k❷:/ | construction |
| **/a/** | /kàt/ | how to polish |
| **/a:/** | /kà:/ | the torn cloth |

Data was recorded using sony digital voice recorder in sound proof language lab of Jawaharlal Nehru University and then was analyzed using PRAAT, Wavesurfer, Goldwave.

## 4 Results and Discussion

As indicated above, the parameters selected were Duration, Pitch and the first three formants (F1, F2 and F3). Results were tabulated; Table 1 and Table 2 show vowel duration of three articulations of the same vowel Table 3 shows the formant values, acoustic space determined by plotting –(F2-F1) against (-F1). Table 4 is for pitch values.

### 4.1 Duration

| **Vowel** | **Duration (m.s.)** | | | |
|---|---|---|---|---|
| | **1 Articulation** | **2 Articulation** | **3 Articulation** | **Average** |
| **/i/** | 0.12 | 0.12 | 0.10 | 0.113 |
| **/i:/** | 0.36 | 0.46 | 0.59 | 0.470 |
| **/ɯ/** | 0.22 | 0.25 | 0.26 | 0.243 |
| **/ɯ:/** | 0.51 | 0.50 | 0.43 | 0.480 |
| **/u/** | 0.13 | 0.15 | 0.14 | 0.140 |
| **/u:/** | 0.49 | 0.55 | 0.42 | 0.486 |
| **/e/** | 0.15 | 0.17 | 0.17 | 0.163 |
| **/e:/** | 0.63 | 0.54 | 0.55 | 0.573 |
| **/ɤ/** | 0.26 | 0.39 | 0.33 | 0.326 |
| **/ɤ:/** | 0.68 | 0.65 | 0.65 | 0.626 |
| **/o/** | 0.17 | 0.20 | 0.20 | 0.190 |
| **/o:/** | 0.53 | 0.47 | 0.53 | 0.510 |
| **/ɛ/** | 0.29 | 0.25 | 0.25 | 0.263 |
| **/ɛ:/** | 0.61 | 0.64 | 0.64 | 0.630 |
| **/ɔ/** | 0.26 | 0.29 | 0.29 | 0.280 |
| **/ɔ:/** | 0.63 | 0.64 | 0.15 | 0.630 |
| **/a/** | 0.15 | 0.12 | 0.15 | 0.140 |
| **/a:/** | 0.53 | 0.52 | 0.52 | 0.523 |

**Table 1** Duration of all the 18, short and long vowels in Thai speech of the selected subject.

| Vowel | Av. of LV | Vowels | Av.of SV | S:L |
|---|---|---|---|---|
| /i:/ | 0.47 | /i/ | 0.113 | 1:4.16 |
| /ɯ:/ | 0.48 | /ɯ/ | 0.243 | 1:2 |
| /u:/ | 0.486 | /u/ | 0.14 | 1:3.47 |
| /e:/ | 0.573 | /e/ | 0.163 | 1:3.52 |
| /ɤ:/ | 0.626 | /ɤ/ | 0.326 | 1:1.92 |
| /o:/ | 0.51 | /o/ | 0.19 | 1:2.7 |
| /ɛ:/ | 0.63 | /ɛ/ | 0.263 | 1:2.4 |
| /ɔ:/ | 0.63 | /ɔ / | 0.28 | 1:2.25 |
| /a:/ | 0.523 | /a/ | 0.14 | 1:3.74 |
| Av. | 0.548 | Av. | 0.206 | 1:2.66 |

**Table 2** Average duration of short and long vowels in the speech of the selected subject

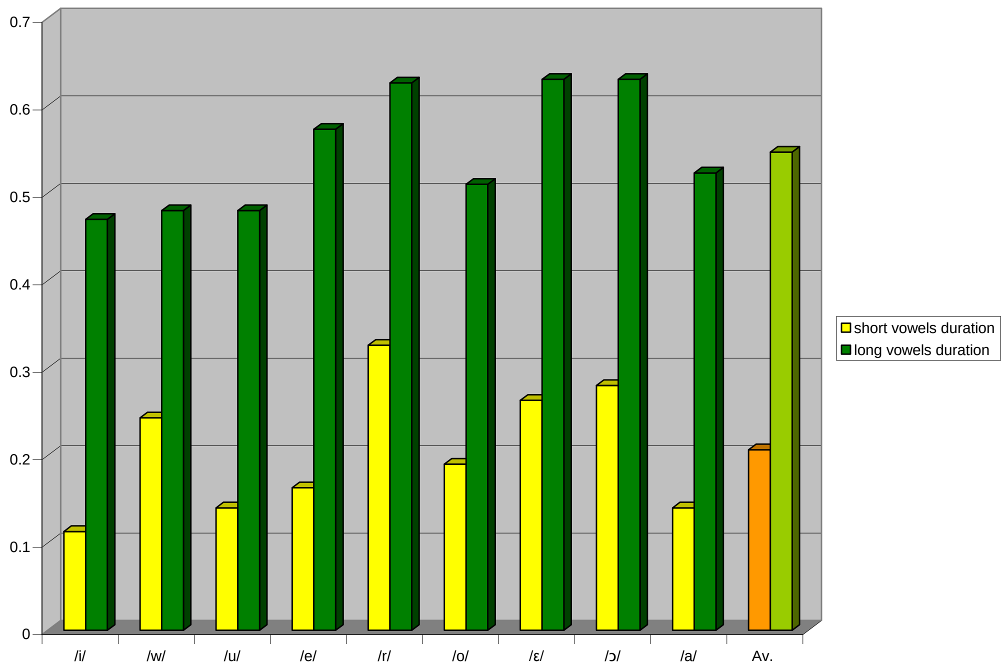



**Figure 1**

The bar chart above shows the average of the three articulations each of long and short vowels in the speech of the selected. All the examples indicate that durational contrast between long and short vowels is prominent and distinctive; the long vowel is at least twice as long as the corresponding short vowel. In case of /i/, /u/, /e/ and /a/ the long vowels are 3.4 times to 4.2 times as long as their corresponding short vowels**.** The half open and half close vowels are 2.25 to 2.75 times as long as their corresponding short vowels whereas the two mid/central vowels are only twice as long as the short vowels. The average of vowel duration for long vowels is 0.548 and 0.206 for short vowels, which is indicated by the last two bars on the bar diagram above. It appears that the durational contrast is the most distinct and well pronounced in case of the extreme/ peripheral vowels, and becomes less and less marked (from 1: 4 to 1: 2) as we move from peripheral to central/centralized vowels.

### 4.2 Pitch

| **Vowels** | **Pitch** |
|---|---|
| **/i/** | 228.09 |
| **/i:/** | 232.65 |
| **/ɯ/** | 230.27 |
| **/ɯ:/** | 225.58 |
| **/u/** | 227.04 |
| **/u:/** | 217.8 |
| **/e/** | 218.01 |
| **/e:/** | 212.69 |
| **/ɤ/** | 214.35 |
| **/ɤ:/** | 219.98 |
| **/o/** | 211.58 |
| **/o:/** | 219.29 |
| **/ɛ/** | 206.56 |
| **/ɛ:/** | 208.53 |
| **/ɔ /** | 211.98 |
| **/ɔ:/** | 213.57 |
| **/a/** | 202.46 |
| **/a:/** | 203.43 |
| **Average** | **216.88** |

**Table 3** - Fo values for all long and short vowels of Thai

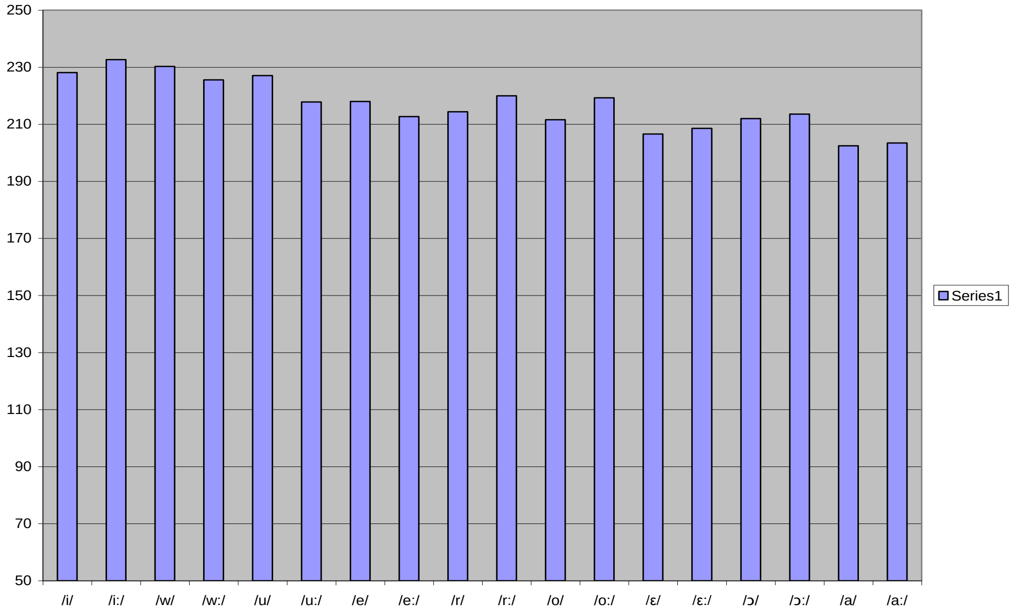



**Figure 2**

As sated earlier all the examples included had vowels with level/ mid tonal phonemes. Hence the range is: 202.45 as the minimum and 232.65 as the maximum pitch i.e. only 30.20 Hz; the average value is 216.88 with a range of 216.88 +16 to 216.88 -14Hz. The table 3 above and the bar diagram also indicate that high vowels show slightly higher values of F0 as in case of **i, i:, ɯ, ɯ**:, and **u, u**: pronounced with pitch ranging from 227 to 232.65; the open vowels a and a: both are pronounced with pitch in the lowest range i.e. 202.46, 203.43; further half open and half close vowels have pitch in the middle range of 208 to 220. Since vowel height is associated with the first formant we may say that F0 values appear to be inversely proportional to F1. F0 is plotted against F1 separately for long and short vowels, which shows tentatively, that vowels with higher F1 values have a relatively lower pitch within the range used for the phonemically distinct mid tone. (See Figure 3 below). Vowel /u:/ seems to be an exception and one possible reason could be the choice of a word with a low/ falling tone instead of level tone by the informant.

This needs to be verified with a larger data base including vowels with the other tonal phonemes as well; also including more data from other speakers of Thai language. There appears to be no such correlation of F0 with F2 values.

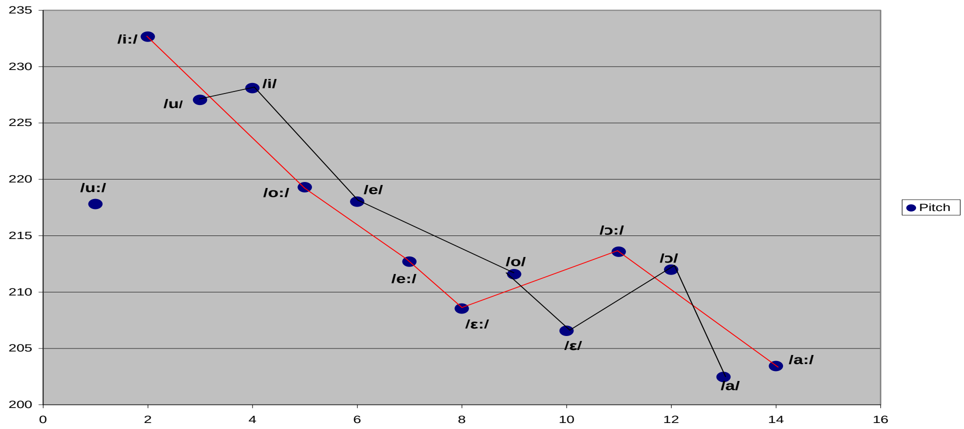



**Figure 3 - F0 against F1 for Long and Short vowels**

### 4.3 Formant Patterns

| Vowels | F1 | F2 | F3 |
|---|---|---|---|
| /i/ | 472.51 | 2798.47 | 3304.33 |
| /i:/ | 424.93 | 2870.62 | 3500.65 |
| /ɯ/ | 452.15 | 1608.96 | 2981.26 |
| /ɯ:/ | 454.4 | 1565.89 | 3062.73 |
| /u/ | 448.05 | 940.44 | 3100.03 |
| /u:/ | 417.62 | 918.76 | 2776.98 |
| /e/ | 533.67 | 2632.84 | 3020.32 |
| /e:/ | 549.45 | 2673.16 | 3058.73 |
| /ɤ/ | 580.83 | 1490.25 | 3051.56 |
| /ɤ:/ | 604.16 | 1414.24 | 3062.16 |
| /o/ | 604.98 | 1164.68 | 3089.15 |
| /o:/ | 492.26 | 1081.24 | 3297.67 |
| /ɛ/ | 618.74 | 2491.45 | 2929.14 |
| /ɛ:/ | 581.09 | 2634.37 | 3075.74 |
| /ɔ/ | 626.23 | 1267.77 | 2860.82 |
| /ɔ:/ | 625.43 | 1262.55 | 2879.98 |
| /a/ | 1050.66 | 1703.28 | 2814.69 |
| /a:/ | 1079.86 | 1612.36 | 2762.71 |

**Table 4** The first three formants for all the 18 vowels in Bangkok Thai

The bar diagrams below show the F1 values of vowels together with duration in figure 4 and F2 values of vowels with duration in Figure 5. It appears that there is very little difference between the F1or F2 values of short and long vowels. The correlation is statistically insignificant at $P>0.05$.

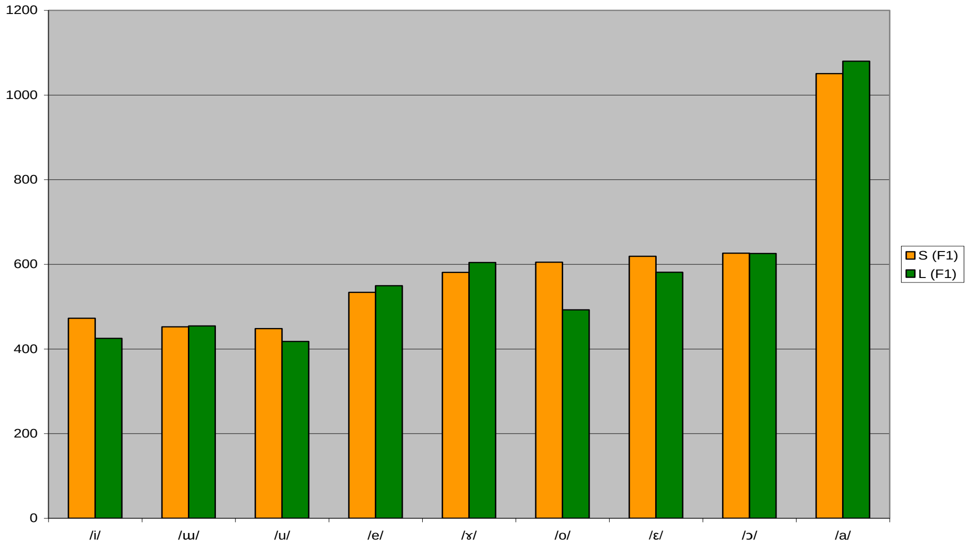



**Figure 4-** F1 of long and short vowels

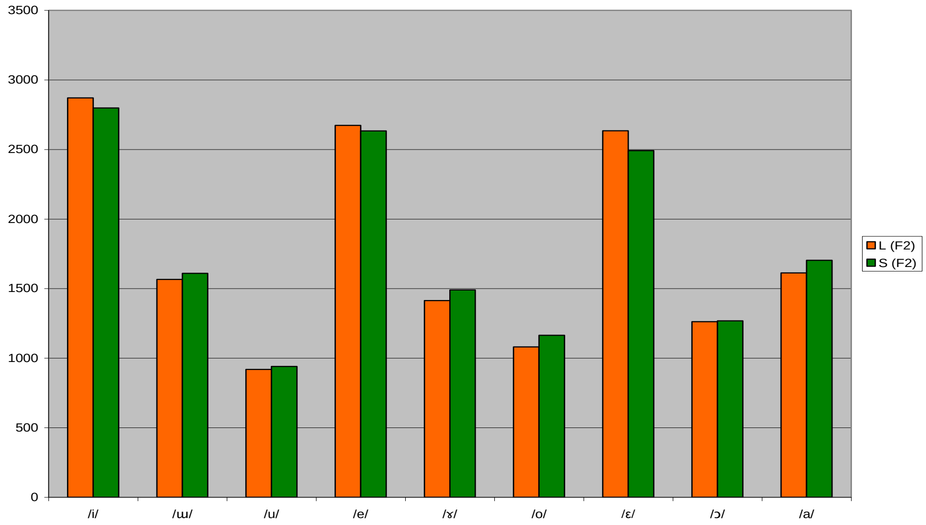



**Figure 5-** F2 of long and short vowels

The Figure 5 shows that there is very little difference of F2 values between long vowels and their corresponding short vowels. The correlation is statistically insignificant at P>0.05. The plotting of F1 and F2-F1 to show the acoustic space of these vowels in section 3.4 below will further highlight these two observations on duration.

### 4.4 Acoustic Space

The acoustic space is obtained by plotting F2-F1 against F1, preferably negative values.

| **Long Vowels** | **-(F2-F1)** | **-(F1)** | **Short Vowels** | **-(F2-F1)** | **-(F1)** |
|---|---|---|---|---|---|
| **/i:/** | -2445.68 | -424.93 | **/i/** | -2325.96 | -472.51 |
| **/ɯ:/** | -1111.49 | -454.4 | **/ɯ/** | -1156.81 | -452.15 |
| **/u:/** | -501.15 | -417.62 | **/u/** | -492.38 | -448.05 |
| **/e:/** | -2123.71 | -549.45 | **/e/** | -2099.17 | -533.67 |
| **/ɤ:/** | -909.42 | -580.83 | **/ɤ/** | -810.08 | -604.16 |
| **/o:/** | -559.7 | -604.98 | **/o/** | -588.98 | -492.26 |
| **/ɛ:/** | -2053.28 | -581.09 | **/ɛ/** | -1872.71 | -618.74 |
| **/ɔ:/** | -637.13 | -625.43 | **/ɔ/** | -641.54 | -626.23 |
| **/a:/** | -532.5 | -1079.86 | **/a/** | -652.63 | -1050.66 |

**Table 5-** Values of –(F2-F1) and –F1 for all short and long vowels of Thai

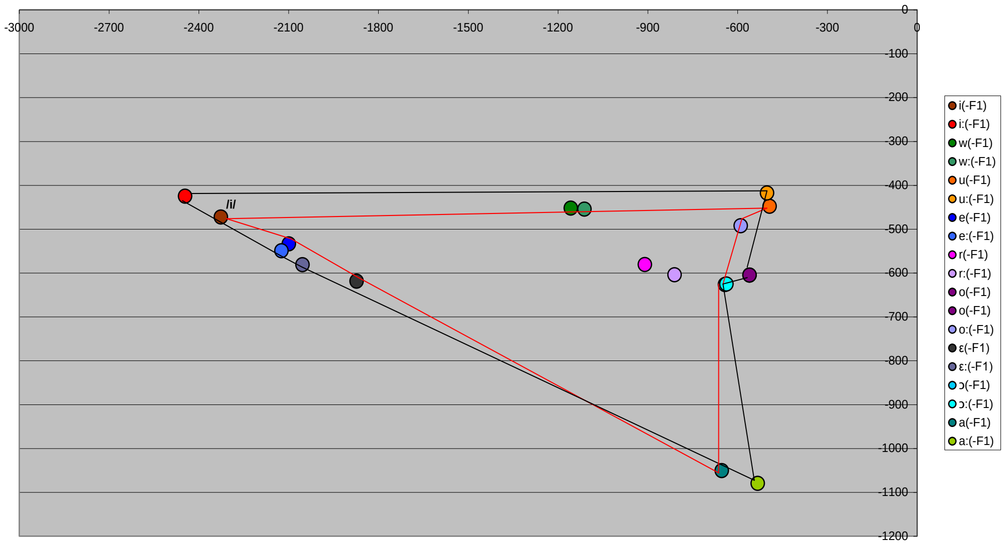



**Figure 6:** –(F1) against –(F2-F1) to show acoustic space of Thai vowels

The table 5 and the figure 6 of all the vowels above show that only four vowels, 2 long and 2 short are central while all the other 14 vowels are peripheral. The long and short vowels are located close to each other on this plot indicating that there is very little qualitative/spectral difference between long and short vowels where duration is the main distinctive feature. The acoustic space of long peripheral vowels is shown in black colored lines and short peripheral vowels in red colored lines and acoustic space is calculated using Irregular Polygon area calculator. The acoustic space enclosed by all the long vowels is 419952.3 and short vowels is 344932.5, which is only 1:0.82. This marginal difference also shows that duration is perhaps the only distinctive feature amongst these pairs of long and short vowels with very little qualitative spectral differences.

This difference of about 18% (1: 0.821) can also be attributed to the spectral difference between the long and short vowels of the two extreme vowels, /i/ and /a/ only. For all the other vowels there is practically no difference in the placing of long and short vowels in this acoustic space. As we saw in the section on duration, these two extreme / peripheral vowels also have maximal durational contrast 1: 4 in /i/ and /i:/, 1: 3.7 in case of a and /a:/. A study on Hindi by Yadav (2009) shows that the acoustic space of the three short vowels in comparison with the acoustic space used in peripheral vowels is 1: 0.28 is just about 28% of the total acoustic space. Formant values for English as in Deterding (1997) were used to calculate the vowel space in English and compared with the acoustic apace covered by the three short vowels i, U and ★ in English, using Irregular Polygon Area calculator. The difference between the long and short vowels acoustic space is 1:0.398 i.e. just about 40% of peripheral vowel space is covered by the centralized vowels. Hence the difference of 18% only seems rather small.

### 4.5 Third Formant (F3)

| **Short Vowels** | **S (F3)** | **Long Vowels** | **L (F3)** |
|---|---|---|---|
| **/i/** | 3304.33 | **/i:/** | 3500.65 |
| **/ɯ/** | 2981.26 | **/ɯ:/** | 3062.73 |
| **/u/** | 3100.03 | **/u:/** | 2776.98 |
| **/e/** | 3020.32 | **/e:/** | 3058.73 |
| **/ɤ/** | 3051.56 | **/ɤ:/** | 3062.16 |
| **/o/** | 3089.15 | **/o:/** | 3297.67 |
| **/ɛ/** | 2929.14 | **/ɛ:/** | 3075.74 |
| **/ɔ/** | 2860.82 | **/ɔ:/** | 2879.9 |
| **/a/** | 2814.69 | **/a:/** | 2762.71 |

**Table 6 -** F3 values of all the vowels

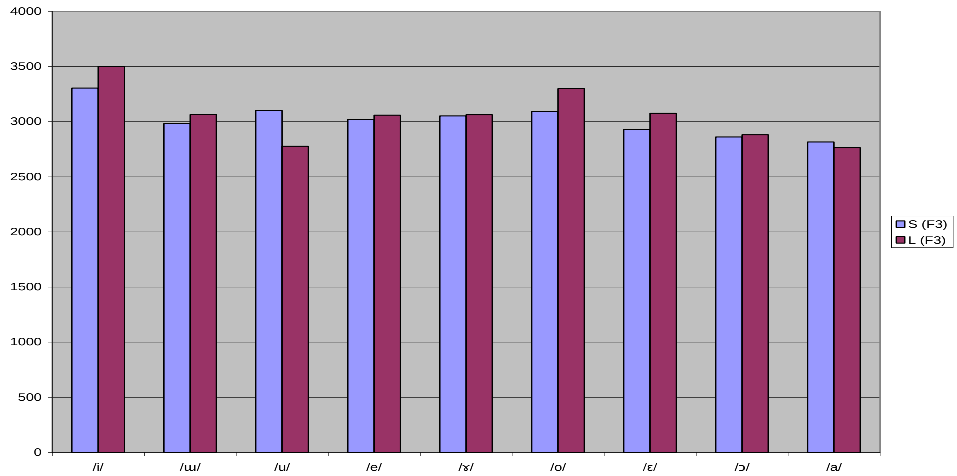
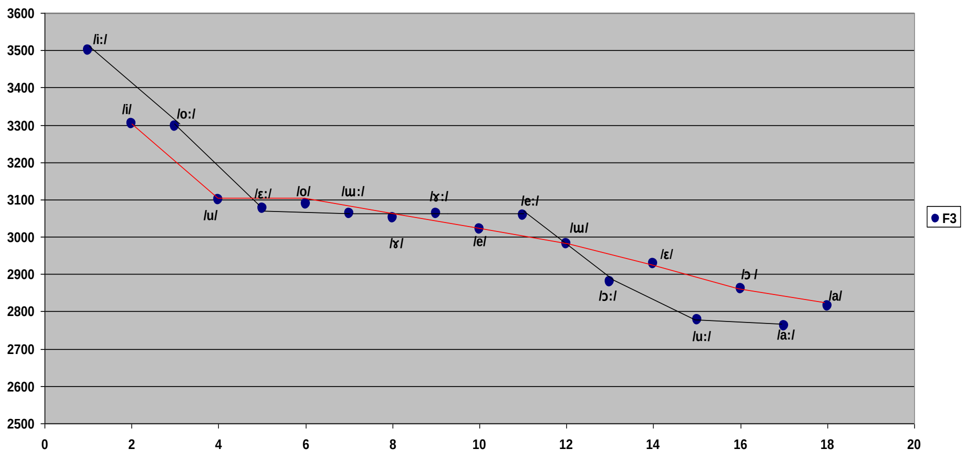


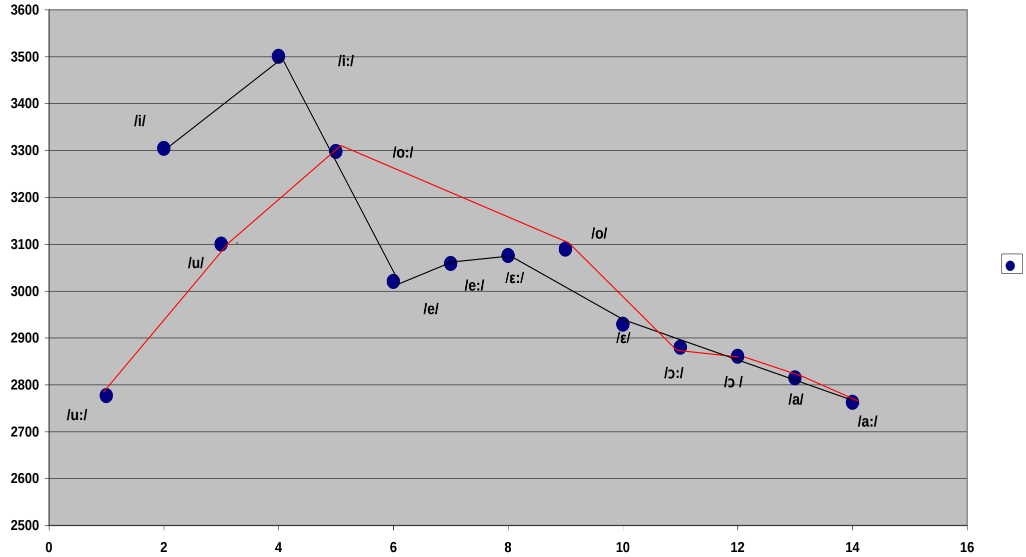

**Figure 7** - F3 values of all vowels.

The bar diagram in figure 5 above shows that there is very little difference between the F3 values of long and short vowels. Since the front high vowels /i:/ and /i/ seem to have the highest F3 values we also tried to find out the correlations, if any between F3 and F2 (for front and back criteria). The Figure 8 below shows F3 against F2 for all the long and short vowels separately. Tentatively, one could say that F3 values go down as we move from front to back vowels, with mid/ central vowels showing roughly the same values; and long vowel /o:/ and short vowel /☜/ not conforming to the principle. F3 correlation with F2 and also F1 needs to be examined further with a larger database from more speakers, with more examples.




← **F2** ←

**Figure 8** F2 against F3 for Long and Short vowels




**← F1 ←**

**Figure 9-** F1 against F3 for Long and Short vowels

## 5 Conclusions

The present study gives a descriptive account of the vowels in Bangkok Thai in terms of the three acoustic parameters- duration, pitch and acoustic space. The important points to note are:

- Nine pairs of long and short vowels have significant durational difference, the long vowels being two to four times longer than their corresponding short vowels.Durational contrast seems to be more pronounced in case of extreme/ peripheral vowels, /i, u, a / which is 1: 4 and becomes less and less marked as we move from peripheral to slightly centralized vowels /e, o and /☜/ which is 1:3, and the least in case of mid/ central vowels /ɯ/ and /ɤ/. This needs to be examined further with a larger data base.
- In Thai language which has five distinct phonemic tones it is interesting to note that the use of one phonemic tone i.e. mid/level tone with all the 18 vowels shows a slightly higher pitch for high vowels which have lower F1 values. In other words F0 values are inversely proportional to F1. This needs to be further studied with examples of all the tones on all the vowels in this language, and perhaps with data from other languages too.
- Acoustic space determined by plotting F2-F1 for front / back criteria against F1 for high–low criteria shows that the long and short vowels are pronounced along the same lines with very little difference in the overall space covered by the long vowels as compared to the short vowels. Unlike Hindi, English, Korean and Japanese languages where shorter vowels are centralized too, Bangkok Thai shows no such spectral/ qualitative difference between long and short vowels. However

in case of two out of the three extreme vowels, /i/ and /a/ which show maximal durational contrast also show a slightly different placing in acoustic space, /a:/ being slightly more open than /a/, and i: being relatively more front and high as compared to /i/.

- Acoustic space covered by the long peripheral vowels is 419952.3 and by the short peripheral vowels is 344932.5, which is only 1: 0.82, once again showing very little difference in spectral quality contrast accompanying durational contrast.This is further proved by the fact that there is no significant difference between the F1 values or F2 values of long and short vowels.
- F3 values seem to have a lower value in case of open vowels and a higher value in case of high/close vowels viz. /i/ and /u/. Mid vowels, both front and back, show comparable F3 values. Hence F3 seems to be inversely proportional to F1, if we examine the front vowels i-e-☜-a and the back vowels u-o-★-a separately. Comparing the two high/close vowels /i/ and /u/ one finds lower F3 values for back vowels and higher F3 for front vowels. F3 values seem to have an interesting correlation with F1/tongue height as well as F2 with front vowels showing a slightly higher F3 than back vowels.

All these findings need to be verified with a larger data base including as many examples of other tones as well as examples from non-tonal languages.

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