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The Standard Khmer vowel system: An acoustic study

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សង្ខិត្តន័យ

ការសិក្សាអាគូស្ទិចលើភាសាខ្មែរកន្លងមក (Henderson 1952, Thomas & Wanna 1987-88, Ratree 1998, Woźnica 2009, Kirby 2014) មិនបានផ្តោតលើគ្រាមភាសាភ្នំពេញជាទម្រង់ស្តង់ដារនៃភាសានោះទេ។ ការសិក្សានេះវិញផ្តោតលើការពិពណ៌នាថ្នាក់លក្ខណ៍ស្រៈនៃស្តង់ដារភាសាខ្មែរក្នុងបរិបទជាក់លាក់មួយលើគ្រាមភាសាភ្នំពេញ។ បើទោះបីជាកន្លងមក មិនមាននិយមន័យច្បាស់លាស់អំពីស្តង់ដារភាសាក៏ដោយ ក៏នៅតែមានសញ្ញាណ «និយាយច្បាស់» (Speaking Clearly) ដែលអាចជួយបញ្ជាក់អំពីគ្រាមភាសាស្តង់ដារនៃភាសាខ្មែរបានដែរ។ ការសិក្សានេះបានបង្ហាញអំពីលទ្ធផលនៃការវិភាគបែបសូរវិទ្យាអាគូស្ទិចលើគ្រាមភាសាភ្នំពេញ។ ការសិក្សានេះបានរកឃើញថា ស្រៈក្នុងភាសាខ្មែរ-ភ្នំពេញ បានបង្ហាញពីលក្ខណៈសទ្ធតា និងសូរសាស្ត្រដូចទៅនឹងប្រព័ន្ធស្រៈក្នុងភាសាខ្មែរស្តង់ដារដែរ។

Abstract

Previous acoustic studies of the Khmer Language (Henderson 1952, Thomas & Wanna 1987-88, Ratree 1998, Woźnica 2009, Kirby 2014) do not concentrate on the Phnom Penh dialect (hereafter PP dialect) as the canonical form of Khmer. This study concentrates on describing standard Khmer vowel distinction in the specific context of the PP

dialect. Although there is no clear-cut definition of "Standard Khmer", the notion of "speaking clearly" (និយាយច្បាស់/nijiəj cbah/) may help us to define standard Khmer dialect. This study reports the results of an acoustic-phonetic analysis of the PP dialect. The study finds that all PP Khmer vowels presented phonemically and phonetically in the standard Khmer vowel system.

Keywords: *standard Khmer, vowel system, duration, frequency, acoustics, Phnom Penh dialect*

Introduction

Khmer, the official language of the Kingdom of Cambodia, is one of the Mon-Khmer subgroups of the Austroasiatic Language family (Schmidt, 1905; Henderson, 1952; Huffman, 1967; Diffloth, 1992). One dialectal variety, Surin Khmer, is spoken by around 1.3 million ethnic Khmer people in the north-eastern and eastern provinces of Thailand. More than one million people of the Khmer ethnic group in the Mekong delta region of southern Vietnam (Minegishi, 2006) speak another variety called Lower Khmer. Linguists have well studied the Khmer has spoken in the northern and southern parts of the Central Khmer (e.g., Suwilai, 1995; Smalley, 1964; Jenner, 1976; Tran Van, 1974; Dhanan and Chartchai, 1978; Hoang Thi, 1986; Thomas, Dorothy, 1987; Phunsap, 1984; Cummings & Thomas, David, 1984; Thomas D., 1976; Pornpen, 1989; Ratree, 1998; Wichitkhachee, 1996; Thach, 1999; Ratree & Jongman, 2005; Kirby, 2013). Central Khmer, however, is less well known. Information about the Central Khmer dialect mainly comes from a studies, such as Aymonier (1874-77); Earst Kuhn (1889); Finot (1902); Maspero (1915); Martini (1946); Henderson (1952); Gorgoniyev (1966); Huffman

(1967); Ehrman (1972); Pinnow (1979); Headley (1977); Sakamoto (2005); Filippi & Hiep (2009) and Haiman (2011). While Khmer dialects in Vietnam and Thailand are relatively well studied, only minimal information is gathered about the Khmer dialect spoken in Phnom Penh, especially in the instrumental phonetic analysis. The studies of Khmer phonemic structure, vowels, and consonants mostly describe the Khmer language in the manner in which it was spoken a long time ago. The current manner of the Khmer language needs to be documented, especially the Khmer vowel system.

The recognized standard version of a language is generally based on a given dialect and can be defined concerning the contexts in which it will be used: media, education, and administration. Nowadays, *'Standard Khmer'* could be more or less assimilated to the Phnom Penh dialect. It is nevertheless not identical to the Phnom Penh dialect (hereafter PP dialect), as speech in Phnom Penh displays several features that are very often seen as differing from Standard Khmer. Moreover, due to modern Cambodian history, most people living in Phnom Penh nowadays come from the countryside (Filippi, 2009). Available descriptive documents describing the Khmer language are published at the French protectorate and later, until 1975. Nothing significant has been written since that time, mainly due to the political turmoil that has characterized Cambodian political life. The descriptions that we have at our disposal rely on two things: 1) the informants (chosen by the linguist). Most of the time, and contrary to the current leading trends in linguistics, the descriptions generally rely on only a minimal number of informants - very often, there is only one informant.

Variation has not yet become part of linguistic research, 2) the nature of phonetics theory at the time of the description. The descriptions, or as far as those particular studies are concerned, a transcription is very often highly dependent on the stage of advancement of phonetic theory. Several linguistic descriptions exist dating back to the French Protectorate (1863 - 1953) and Sangkum Reastr Niyum (1955 - 1970). These varying descriptions might not be good sources for determining standard Khmer pronunciation, but they may help us understand what kind of speech is acknowledged as valuable at that time. Studies from Finot (1902) and Maspéro (1915) are, of course, full of exciting information, but they are mute as far as any localization is concerned, and they do not consider that one Khmer variety could be preferred over another one. Martini's description (1946) is the first to mention the local source of its description, Phnom Penh. The choice to focus on the Phnom Penh dialect is not based on any evaluation that it was more prestigious than any other was. However, as Martini explains: "As a base for our description, we selected the Phnom Penh dialect. It stands in between Battambang, which is linguistically more conservative and the diphthongization of Cochin-china"(Martini, 1946).

Many authors have proposed vaguely distinct analyses of the PP Khmer vowel system. This vowel system may be in fragment in the view of the fact that the full degree of variation in pronunciation between individual speakers (Martini 1946, Henderson 1952, Pinnow 1980), even within a dialectal region (Earst Kunh 1889, Noss, 1968, Huffman 1968, Sakamoto 1977, Minegishi 1986, Ratree 1998, Filippi & Hiep 2009). The PP Khmer vowel

system is undoubtedly one of the most autochthonous because of its richness and complexity (Martini, 1946). The phonological opposition of the a-series and b-series, inherent vowels /ɒː/ and /ɔː/, and first register and second register are the characteristics of the PP Khmer vowel system (Finot 1902, Schmidt 1905, Maspero 1915, Martini 1946, Henderson 1952, Gorgoniyev 1966, Huffman 1968, Sakamoto 1977, Pinnow 1980, Diffloth 1984, Jenner 1987, and Ratree 1996). The characteristic of phonological opposition encompasses almost all vowels into the vowel splits, with few exceptions. The vowel groups or vowel splits, which differentiated by phonation types or voice qualities, are transformed by a normal or head voice, first register /ɑː/, and a deep slightly breathy or sepulchral voice, second register /ɔː/, accompanied by high pitch and dilation of the nostrils or lower pitch (Henderson, 1952).

A notable vowel distinction has been classified due to the tongue height and the participation and non-participation of the lips in its articulation and vowel length (Gorgoniyev, 1966). Consequently, the exact number of vowel phonemes is still subject to controversial discussions across dialectal variation. Moreover, the number of vowel nuclei and its values diversifies between dialects; differences exist even between the Standard Khmer vowel system, PP dialect, and that of the BS dialect or TK dialect on which the standard is based (Noss 1968, Sakamoto 1977, Minegishi 1986, Ratree, 1998). According to Martini (1946), PP Khmer vowel phonemes have only twenty-eight at that time. According to Henderson (1952), there are thirty-two vowel phonemes at that time of Khmer, placing the PP Khmer language

between Pacoh (30 vowels) and Bru (41 vowels) in terms of richness of the vocalic inventory. The other linguists Gorgoniyev (1966), Huffman (1968-70), Prom Mol (2003), Sun (2003), and Filippi & Hiep (2009) have, therefore, classified by only thirty-one vowels of PP Khmer vowel system with ten long, eight short monophthongs, and ten long, three short diphthongs.

The PP Khmer diphthong never has a subject of any unique research[1]. A phonological analysis of PP Khmer diphthong is based on falling and rising pitch contour and falling and tense or gliding[2]; it has a phonological significance of their own, varied from the other monophthongs historically (Henderson 1952, Gorgoniyev 1966, Huffman 1970). The PP Khmer diphthongs typically consisted of one steady-state and an offglide. The first component of these diphthongs has the same comparable value as the simple monophthongs, but the second component simply points to the target's direction shorter than the first component. However, the contrast is precise in short diphthongs; the first component of short diphthongs is shorter than the second component or offglide[3]. The number of PP Khmer diphthongs seems to be more abundant than other mutual dialects such as northern Khmer and southern Khmer. The exact number of PP Khmer diphthongs may be debatable from various approaches. According to

[1]Maspero (1915) described the latter diphthong as “primary or primitives”and the former as “secondary or posteriors”. “Primary” diphthongs exist as they hae in the past, whereas “secondary” diphthongs have developed from simple vowels or even from clusters consisting of the consonant and vowel as the morpheme-final sequences.
[2]Henderson (1952) and Gorgoniyev (1966) used the same pitch contour as a falling and rising diphthong. However, Huffman (1970) described Khmer diphthongs as phonologically significant arising from a falling and tense contour. They involve a notable movement of the tongue from a high position to lower one and from the lower position to the higher one.
[3]Huffman (1970) described (Central) Khmer long monophthongs and long diphthongs, which are equivalent in length, are treated as sequences of two short vowels. The short diphthongs, which are equivalent in length to short vowels, have no long counterparts, and must be treated as unit phonemes.

Henderson (1952), there are twelve long diphthongs (three short diphthongs); most of them are the falling-pitch. According to Gorgoniyev (1966), there are ten long diphthongs (only one short diphthong) of PP Khmer by haft of them are falling-pitch. According to Huffman (1970) and Filippi (2009), PP Khmer has thirteen diphthongs with three short diphthongs. The table below is a diphthong illustration by various authors and various transcriptions.

Table 1. Khmer diphthongs

Graphs	អ៊ា/អ៊ៀ	អ៊ើ	អ៊ែ	អ៊ួ/អ៊ូ	អ៊ូ	អ៊ំ/ះ	អោ	អ៊ើ	អ៊ឿ/អ៊ឿ	អ៊ឺ	អ៊ាក់	អ៊ួក់	អាក់
Henderson(1952)	iə/iə$^{\downarrow}$		æ$^{\downarrow}$	uə/ùə$^{\downarrow}$		ɔ̀ə$^{\downarrow}$	ao$^{\downarrow}$	aʀ$^{\downarrow}$	wə/ẅə$^{\downarrow}$			ŵə$^{\downarrow\uparrow}$	ĕə$^{\uparrow}$
Gorgoniyev(1966)	i:ə/ɐ:a$^{\downarrow}$		a:e$^{\downarrow}$	u:ə$^{\downarrow}$	o:u$^{\uparrow}$	ɔ:a$^{\downarrow}$	a:o$^{\uparrow}$	a:ə$^{\uparrow}$	ɯ:ə$^{\downarrow}$		ĕə$^{\uparrow}$		
Huffman (1970)	iə$^{\downarrow}$	ei$^{\uparrow}$	æ$^{\downarrow}$	uə$^{\downarrow}$	ou$^{\uparrow}$	ɔə$^{\downarrow}$	ao$^{\downarrow}$	æ$^{\downarrow}$	ɨə$^{\downarrow}$	əi$^{\uparrow}$	ĕə$^{\uparrow}$	ŭə$^{\downarrow\uparrow}$	ŏə$^{\downarrow\uparrow}$
Filippi (2009)	iɜ$^{\downarrow}$	ɛe$^{\uparrow}$	æ$^{\uparrow}$	uɜ$^{\downarrow}$	ou$^{\uparrow}$	oa$^{\downarrow}$	ao$^{\uparrow}$	aɜ$^{\uparrow}$	ɨɜ$^{\downarrow}$	ɜə$^{\uparrow}$	ĭɜ$^{\downarrow}$	ŭɜ$^{\downarrow}$	ĕa$^{\downarrow}$
This study	iɜ/iə$^{\downarrow}$	ɛe$^{\uparrow}$	æ$^{\uparrow}$	uɜ$^{\downarrow}$	oʊ$^{\uparrow}$	oa$^{\downarrow}$	ao$^{\downarrow}$	aɜ$^{\downarrow}$	ɨɜ$^{\downarrow}$	ɜə$^{\uparrow}$	ĭɜ$^{\downarrow}$	ŭɜ$^{\downarrow\uparrow}$	ĕa$^{\downarrow}$

This study, a phonological analysis of spoken PP Khmer diphthongs, proposes that there are only ten long diphthongs, not thirteen or fourteen:/iɜ$^{\downarrow}$, iə$^{\downarrow}$/, /ɨɜ$^{\downarrow}$/, /uɜ$^{\downarrow}$/, /aɛ$^{\downarrow}$/, /aɜ$^{\downarrow}$/, /aɔ$^{\downarrow}$/, /oa$^{\downarrow}$/, /ɛe$^{\uparrow}$/, /oʊ$^{\uparrow}$/, /ɜə$^{\uparrow}$/and finally three short diphthongs; /ĭɜ$^{\downarrow}$/, /ŭɜ$^{\downarrow\uparrow}$/, /ĕa$^{\downarrow}$/ of PP Khmer. The analyses (e.g., Huffman 1970, Filippi and Hiep 2009) describe 13 diphthongs, and three short diphthongs, which are well-transcripted. Huffman (1970) and Filippi (2009) transcribed the words ទាប and ទៀប by the same diphthong as /tiɜp/, which is representative of some parts of the PP dialect. However, two words are realized separately as /iɜ/ in ទាប /tiɜp/

“short” and as /iə/ in រទៀប /tiəp/ “custard apple” in other dialects of Khmer, including dialects used in the southern part of Phnom Penh.

There are other modern classifications of the Khmer vowel system, such as Khoun Sokhompou (1970). According to Khoun's dissertation, which was defended in Germany, the Khmer vowel system has 25 monophthongs and eight diphthongs. On the other hand, Gorgoniyev (1966) determined 31 monophthongs and diphthongs. Most importantly, according to Jean Michel Filippi (2009), there are about 31 Khmer vowels, 18 monophthongs, and 13 diphthongs. According to Huffman (1970a-b), there were only ten long monophthongs, and only eight long monophthongs have short counterparts[4]. For diphthongs, Huffman defined there are 13 diphthongs.

Notably, the pairs listed (Headley Jr. 1977; Huffman 1970b) form a proportional and one-dimensional contrast. The phoneme /i/ occurs only in loanwords from Sanskrit and Pali. It either has in complementary distribution with /iː/or has an alternative pronunciation, as in ទីប/tip/"magical" vs. ទិព្វ/tɨp/"divine" (Headley Jr. 1977). The distribution of /i/ makes it impossible to find reliable sample words for the study, hence the omission of /i/ from the data set. This phenomenon could be part of the standardized character of modern Khmer pronunciation. The symbols used to describe the Khmer language are mainly derived from vowel signs. For instance, the uses of the following symbols [ɵ] [ɜ] [œ] to transcribe Khmer central vowels are

[4]Huffman argued that not all long monophthongs have short counterparts.

uncommon. These symbols are, in fact, the front labialized French vowels that are different from the Khmer central vowels [ɨ] [ɘ] [ɜ] in modern Khmer. This simply means that the French language description strongly influenced a previous vision of Khmer phonetics. Previously, Henderson had contributed another highly emblematic description in the article: "*The Main Features of Cambodian Pronunciation*." Henderson raised many problems related to the Khmer vowel system in terms of registers. Within this description of the Khmer vowel system, the useful features and terminological explanations did not describe standard Khmer pronunciation at that time. The presence of phonological opposition indicates that: breathy voice registers vs modal voice registers. The natural explanation for this is that Henderson's main informant was a Khmer scholar, Keng Vannsak[5].

Table 2. Henderson's vowel classes

	First Register				Second Register		
		Unrounded		Rounded		Unrounded		Rounded
		Front	Back			Front	Back	
Long(Open and closed syllables)	Close	e		o	Close	i	ŭɯ	ŭ
	Open to Close	æ	ɐr	ɑo	Half-open	ĕ		ŏ
	Close	a			Open	ĕ	ɐr	ŏ
	Close to Open	iə	ɯə	uə	Close to open	iə	ŭə	ŭə
Short(Closed Syllables Only)	Close	(e)	ɤ	o	Close	(i)	ŭɯ	ŭ
					Close to centre			wə
	Open	a		ɔ	Open to center	ĕə		ɔə

Another critical description is Huffman's (1970a-b) description. This description is more phonemic than the phonetic description. He did not use

[5]He was a high-level Cambodian intellectual, very concerned with language, literature, and civilization questions. He later wrote "Principles of Creating New Words". As Henderson's informant, Keng Vannsak did not speak using his own Kampong Chhnang dialect but derived his high standard of pronunciation from the Khmer script.

the International Phonetic Association (IPA) symbols Stricto-Sensu but a mixture of International Phonetic Alphabet (IPA) and traditional American Phonetic transcription. For instance, how consonant clusters are transcribed indicates that Huffman is not going deep into phonetic detail - he did not mention the small details distinguishing C1 & C2. Another interesting transcription is Huffman's treatment of the velar consonants [k] and [ŋ] in cases of front vowels /iː, eː, ɛː, aː/. Here each minimal pair relies more on the script than on the actual pronunciation; he did not consider palatalization after the front vowels and the opened diphthongs. Of these cases, for example, there are so many mistakes in transcription, such as:

ជីក "to dig" in actual pronunciation: /ciːc/, and in Huffman's transcription: /ciik/; ចេក "banana" in actual pronunciation: /ceːc/, and in Huffman's transcription: /ceek/; ជែក "to carry on" in actual pronunciation: /rɛːc/, and in Huffman's transcription: /rɛɛk/; កាក់ "coin" in actual pronunciation:/kaʔ/, in Huffman's transcription: /kak/.

Table 3. Huffman's vowel system

Long vowels	/ ii, ee, ɛɛ, ɨɨ, əə, aa, ɑɑ, uu, oo, ɔɔ/
Long diphthongs	/ iə, ɨə, uə, ei, əɨ, ou, ae, aə, ao, ɔə/
Short Vowels	/ i, e, ɨ, ə, a, ɑ, u, o/
Short diphthongs	/ ĕə, ŭə, ŏə/

The determination of the Khmer vowel system is pointed out by an essential document, Y.A. Gorgoniyev's (1966) "*The Khmer Language*" that was translated from Russian to English Language in 1966 by V. Korotky. Gorgoniyev focused on Khmer phonetics and sound patterns of the Khmer

spelling system. Gorgoniyev's informant was Dr Long Seam. By investigating the Khmer vowel structure, Gorgoniyev found 21 monophthongs and ten diphthongs in the below minimal pairs, diphthongs, and vowel charts.

Table 3. Gorgoniyev's vowel classes

	Front	Central	Back
1	iː (i)	ɯː ɯ	uː u
	iːə	ɯːə	uːə
2	eː	ə̯ː	o̯ː or
	(e̯ːɑ)		oːu
3	eː (e)	əː ə	oː o
4	ɛː		ɔː ɔ
			ɔːɒ
5	aː a		ɒː ɒ
	aːe		ɒːo
		aːə	

This paper presents the Khmer vowel system in an acoustic-phonetic analysis. It also classifies the modern Khmer vowel system using current pronunciation and numerical descriptions on monophthongs and diphthongs. The main reason for selecting this vowel inventory to represent the standard Khmer vowel system is that there is a current trend of phonemic changes in modern Khmer pronunciation. Previously, the front vowel /i/, and /ɛ/ and back open-mid vowel /ɔ/ did not commonly occur in the closure syllabic structure of Khmer (Henderson 1952, Gorgoniyev 1966, Prom Mol 2012, Filippi & Hiep 2009). However, in the Phnom Penh dialect, there is an occurrence of /i/, /ɛ/ and /ɔ/ in such these words កាពិ/kaːpiʔ/"cheese", ម៉ែបិ/mɛc/"how" and ជនៃ /cɔn/"people".

To conclude previous studies and to focus the research outcomes, 21 long and short monophthongs/ iː i, ɨː ɨ̆, uː ŭ, eː e, ɛː ɛ, aː a, ɘː ɘ, oː o, ɔː ɔ, ɒː ɒ, ɜ / and 13 long and short diphthongs /iɜ/: /ɨɜ/ ː /uɜ/ ː /aɛ/: /aɜ/: /aɔ/ː /oa/: /ɛe/: /oʊ/: /ɜɘ/, /iə̆/, /ŭɜ/, /ă̆a/ of the Phnom Penh dialect were identified by placing them into a frame sentence. This vowel class is analyzed by an acoustic cure of the modern Khmer vowel system's sound patterns. The results of the present study will be presented in linear regression and chart.

Methods

Subject and materials: This paper analyzes the Khmer vowel system in terms of frequency domain and duration. First, native speakers who have permanent residence in Phnom Penh were selected. They were asked to pronounce many words, formally and casually. They were recorded using a computer program: Praat software with 32 bits and 44100 Hz sampling voice recording rate. The context of the recording was critical. To avoid our informants feeling uncomfortable or nervous in the recording room, we spent around 30 minutes explaining our recording procedures, how to place their mouth in front of the microphone, how to read the frame sentence, and how to repeat the sentence.

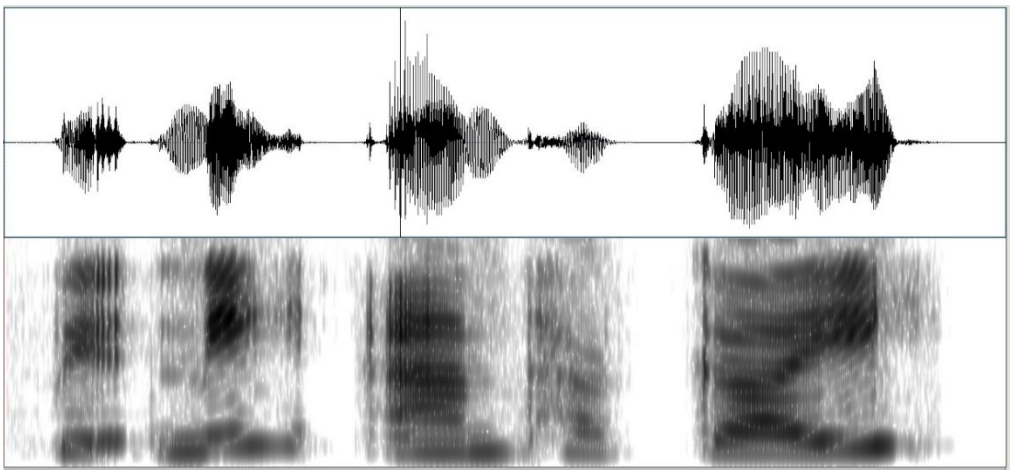
Twenty-one native Khmer speakers (12 females) from different backgrounds, occupations, and residences were selected for casual observation during the first stage of the Clearly-Speak observation procedure. They were assigned to engage in formal and casual speech with 168 lexical items. They repeated the items two times each. This process was designed to determine who had a clearer speech. As a result, only 4 Khmer

native speakers (2 females) from Phnom Penh were selected as the informants in this study. They possessed a clear voice and had experience in using a microphone and talking naturally in front of it. Their age ranged from 20 to 50 years old with either a bachelor or master degree and had been working in administration, education, or the media. Next, the participants were recorded by reading isolated words from a list. Then, they were asked to read 61 lexical items in a formal reading manner three times. For instance, they recorded the following frame sentence: ពាក្យនេះ អានថា...។ /piəʔ nih ʔaːn tʰaː .../, then they pronounced the designated word. Here, we listed 61 lexical items, including 34 vowel nucleus clusters with 21 monophthongs/ iː i, ɨː ɨ, uː ŭ, eː e, ɛː ɛ, aː a, əː ə, oː o, ɔː ɔ, ɒː ɒ, ɜ / and 13 diphthongs /iɜ/, /ɨɜ/, /uɜ/, /aɛ/, /aɜ/, /aɔ/, /a/, /ɛe/, /oʊ/, /ɜə/, /iŭ/, /ŭɜ/, /ăa/.

Experiment: The average duration of 34 vowels was measured in the monosyllabic and polysyllabic structures. The vowel durations were measured in milliseconds (ms). The measurement of vowel duration was used for both the visual and auditory cues. The auditory cues can be interpreted differently in different studies. This study was used to investigate all vowels' actual duration consisting of acoustic cues on the sound spectrum unit. Furthermore, voice onset time (VOT) was defined as vibration separations, specifically describing consonant and vowel nuclei. The time between samples was 0.09 seconds (90 milliseconds). The potential time resolution of a recording on Praat Windows is reported as around 112.848980 seconds. The words' position and function within the frame sentence were used to avoid the vowel nucleus deformation caused by a lack

of sentence stress. Some vowel distribution patterns are complicated to find words for that provide an appropriate environment for the vowels commonly used by the Khmer native speakers.

Figure 1. Praat speech synthesizer and automatic alignment



The unnatural word stress, vowel duration artifacts, and even refusal to read a word ("There is no such word") often were caused by the speakers' lack of familiarity with a lexical item. Whenever possible, such gaps in data were filled by the vowel in question taken from different words and sentences. This particular issue concerns the second measurement. Not all of the vowel samples were featured in the research because Khmer sequences of the type /VA/ (vowel + approximant) are traditionally interpreted as two-phoneme sequences (Huffman 1970a-b). The graph illustration of the results shows how vowel duration could be interpreted in complex word classes and sequences.

Segmentation: Our acoustic data was annotated and segmented using Praat 6.0.36. (2016) speech synthesizer and automatic alignment. This application was used to measure the total frequency and duration of all assets V1 and V1+V2 in the nucleus cluster, accommodated by C1 release or plosive, final consonant closure, and possibly a release in transitional vocoid or syllabic rime. Our analytical data were stored and analyzed according to articulation, vowel variation, and the linear regression and plotted using Microsoft Excel 2016. Acoustic cues and spectral combinations were highlighted by observing a periodic waveform, an increase in signal energy at C1 release or plosive, and a formant structure region. In Khmer's syllabic structure, the final consonants' phonemic structure's abstract element was always a closure consonant, unreleased, with an invisible spectrum.

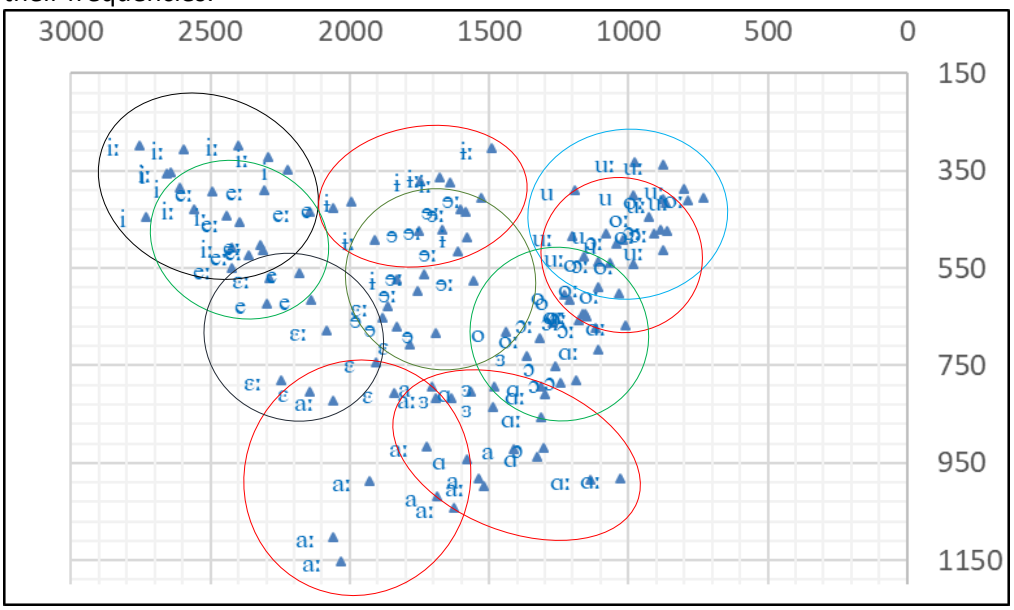
Analysis: The results were analyzed by linear regression, specifying the intercepts for subjects and items. The use of main slopes, where appropriate (where models converge), is noted. The results were displayed in graphs and charts showing average frequencies, F1 and F2, and vowel duration in the Khmer vowel system based on articulations and acoustic characteristics.

Results and findings

This paper displays an analysis of vowel quality according to acoustic characteristics. This study reveals that both F1 and F2 represent the various vowels' articulation in the Phnom Penh dialect and the standard Khmer dialect. A graph was created to display the Khmer vowels space by comparing these speakers' frequencies, F1, and F2. However, this paper is

only an outreached statistical study for determining Khmer vowels' characteristics and their function in acoustic-phonetic data.

Figure 3. Formant frequencies (f1/f2) of Four Native Khmer speakers (2017, PP Dialect), the formant values of all speakers enclosed in circles have converted to the scale of differences between those speakers with closeness and openness of the syllables. The vowel's places of articulation have been allocated with the circles by their frequencies.



The above diagram shows the place of articulation of vowels in the vertical axis that is generally linked with high, mid-high, mid-low, and low vowels, a tongue position in the vertical axis. Another explanation relies on the tongue movement along the horizontal axis and allows the front, central, and back vowels' specifications. The above diagram shows only long and short monophthongs.

In the experimentation of vowel formants, data is organized according to maximums and minimums of vowel frequencies. The above table shows the place of articulation of vowels with regards to the characteristics of frequencies. The explanation is mainly focused on how F1 can be modified by the openness and closeness of vowels.

The table shows that the maximum of long vowels is higher than the short vowels by openness. On the contrary, the minimum of both the long and short vowels is reduced, and it indicates that the short vowel is lower than the long vowel by closeness. Vowel frequency, F2 is also structured by the front, central, and back vowels according to the tongue position and its movements in the vertical axis. The maximum number of long vowels is higher than short monophthongs. Conversely, the minimum of long monophthong is lower than short vowels. The long front monophthong seems to be determined more by position at the front than by shortness of length; the short back monophthongs are shown further back than the long monophthongs.

Table 4. Standard Khmer monophthongs (Max and Min)

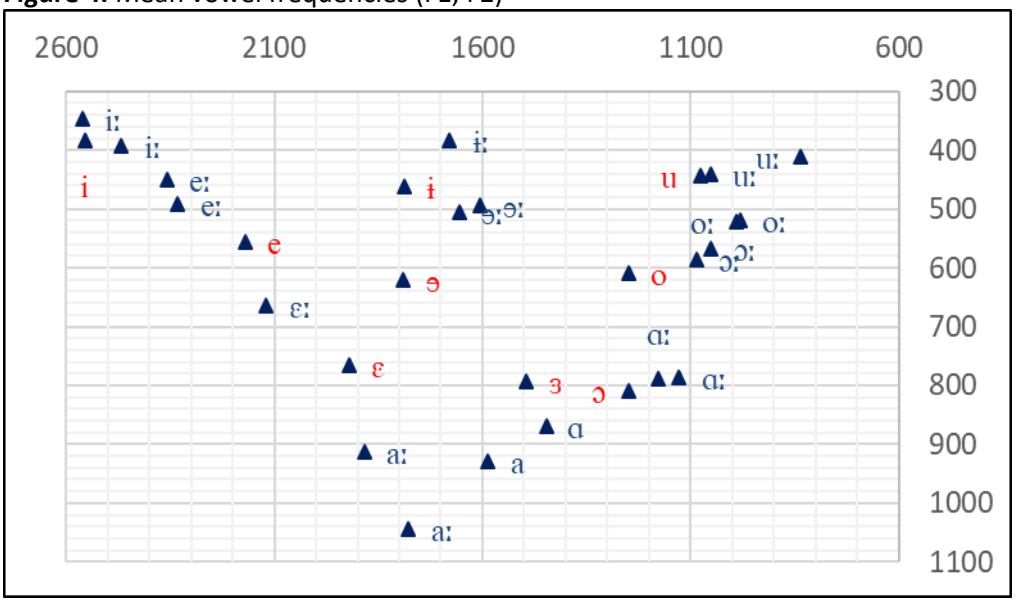
Max/Min	F1	F2
Max	1152	2755
Min	297	731
Max	1019	2731
Min	347	983

Average Khmer Monophthongs. A Standard Khmer vowel system chart was created by the horizontal and vertical axis based on vowel frequencies. This analysis reveals a few questions about the inconsistency in vowel charts and vowel places that occur only in opened-syllabic structures.

Figure 4 shows the average vowel frequencies and indicates the value of the first and second frequency of all 21 monophthongs: 10 long monophthongs and 11 short monophthongs. According to the value found for F1, all long vowels were lower than short vowels with two exceptions. The long vowel [aː] in the opened-syllabic structure is higher than the short vowel [a], and the long vowel [aː] in a closed syllable is lower than the short vowel [a]. These frequencies revealed that

the coda or final consonant could modify vowels in the closed syllable. The coda or final consonant in the syllabic structure can affect the vowel nucleus, such as vowel quality and length. These results show that long vowels are more closed than short vowels, except [a:]. Long vowels are higher in quality.

Figure 4. Mean vowel frequencies (F1, F2)



Most importantly, in terms of backness, all short back vowels are further in front of their counterparts. With frontness, long vowels are more back than their counterparts. For central vowels [ɨː, ɨ; ɘː, ɘ], long vowels are centralized in comparison to front and back vowel frequencies. The short vowel [a] seems to be more centralized comparing to other vowels.

Long and Short Diphthongs. This part was the most challenging part of the acoustic measurement and analytical process of the Khmer vowel system, especially for diphthongs. As a result, the first element of standard Khmer diphthongs was higher than the second element of its combination. The descriptive approach of vowel frequencies indicated, both in the spectrogram and sonogram, that the second vowel unit (V2) was dominated, in two out of three cases by the first vowel unit (V1)

of a diphthong. Thus, the frequencies, F1 and F2, mainly represented only the first vowel unit in the vowel space in Figure 5[6].

Figure 5. Mean of long diphthongs

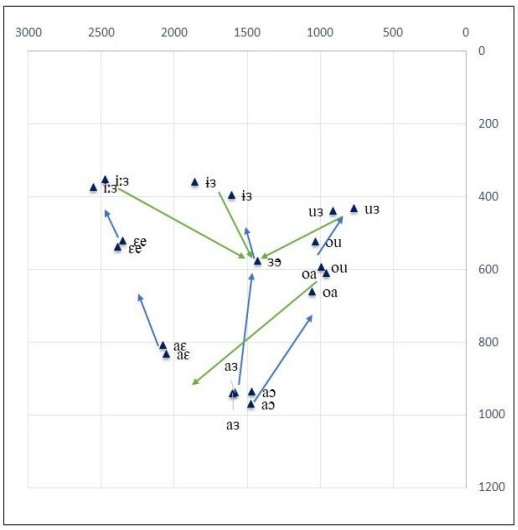
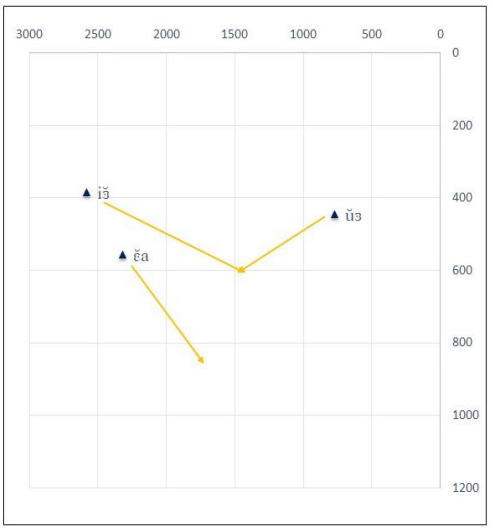


Figure 6. Mean of short diphthongs



In Figure 6[7], there are three short diphthongs. The chart shows how these recorded and measured by a computer program to analyze the apparent tendency of articulation and experimental phonetics of Khmer short diphthongs. The coarticulation of short diphthongs was too short to distinguish, and it was challenging to discover each frequency and duration. Nonetheless, the spectrogram shows no difference between the long and short duration of each comparison.

[6]Note: The figure was formed by drawing arrows from the average /f1, f2/ measurements measured at 80% of first vowel duration (the tail of the arrows) to the corresponding values measured at 20% of vowel duration (the second vowel combination). The averages for short diphthongs ranged from 0.14 seconds to 0.32 seconds with a respective sampling rate of 44100 Hz and 32 bits.

[7]Note: The figure was formed by drawing arrows forms the average /f1, f2/ measurements measured at 80% of vowel duration (the tail of the arrows) to the corresponding values measured at 20% of vowel duration (the second vowel combination). Contrary to the long diphthongs' duration, short diphthongs commonly occur in the closure of syllabic structures /-h, -k, -ʔ/. The short diphthongs duration is similar to the long diphthongs' duration in the same contexts of syllabic closure structures. The average for short diphthongs ranked from 0.12 seconds to 0.14 seconds with a respective frequency sampling rate of 44100 Hz and 32 bits.

However, concerning speech perception and nucleus measurement, we found a difference between long diphthongs and short diphthongs in terms of the depth of pronunciation, closure, and openness, and release syllabic structure.

Vowel Duration. The long monophthongs ranged from 0.9 seconds to 0.27 seconds, and short monophthongs are from 0.6 seconds to 0.11 seconds. The closed syllables were usually shorter than opened syllables. The syllable illustrations are characterized simply to justify the acoustic data. If transitional elements are part of the syllable's phonological specification, we might expect to observe an increase in nucleus clusters' duration containing the pure vowel segment and closure syllable (C+ V1 +C). In the closure syllable, the most detailed analysis was the separation of the vowel nucleus's vibration and the plosive consonant at the end of the word, excepting fricative and even nasalized consonants that could be separated by voice onset time. Both sonograms and spectrogram did not show the nucleus and coda's boundary in the Standard Khmer syllabic structure.

Figure 7 shows the vowel duration that is measured based on isolated words and frame sentences. The average of vowel duration is recorded in milliseconds (ms) and utilized spectrograms and waveform plots to analyze such features of the acoustic signal, as periodicity (instrumental cue, considering the ubiquity of /V+ Fricative Consonants/ and /V+ nasal Consonants/ syllable offsets in Khmer), /V+h/ formant patterns typical of some vowel categories and sound wave amplitude dynamics. Part of the waveform envelope is schematically represented on a spectrogram and sonogram. (A) The curve indicates a surge of voice wave amplitude. The transition from the periodic [a] to the non-periodic [h] is also clearly visible. (B) The last impulse of [a] is relatively weak; therefore, it is not counted in the vowel duration. The vowel duration data obtained are sorted and averaged

according to vowel type (long and short monophthong and long and short diphthong).

Figure 7. Mean duration of monophthongs (short and long)[8]

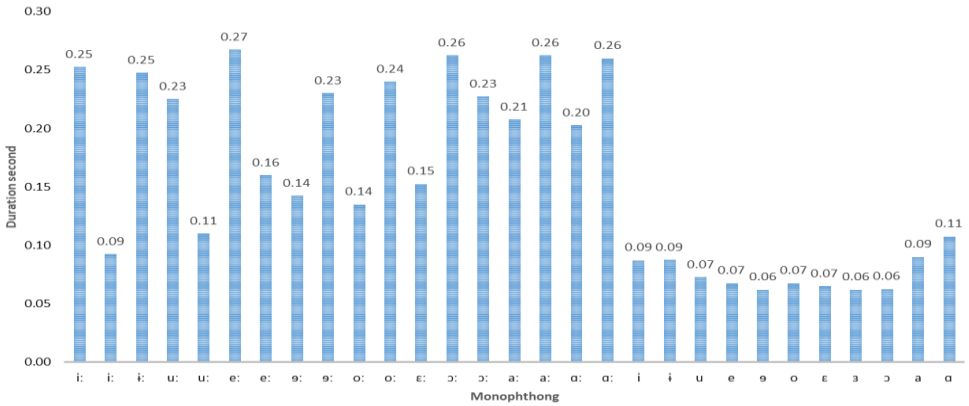
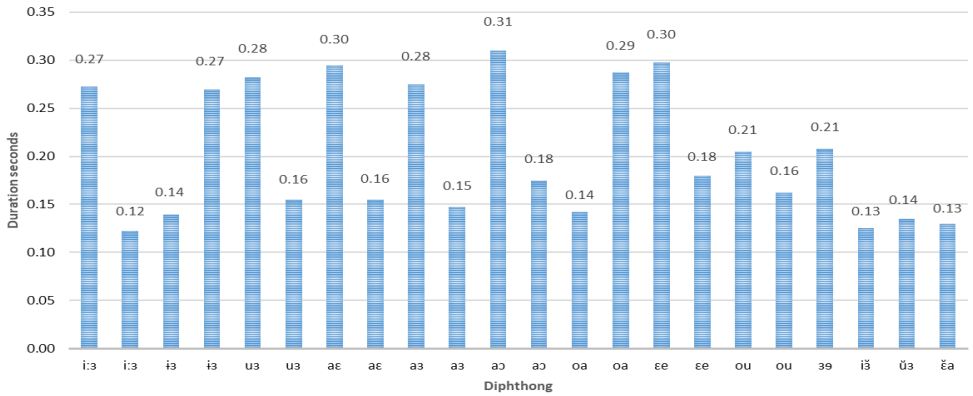


Figure 8. Mean vowel duration of diphthongs (short and long)



The patterns thus yielded are generally accordant with the classification of Khmer vowels. The ratio of the average duration of short to long vowels to long and short diphthongs is 76ms: 204ms: 215ms and 130ms. The table also shows the mean duration of all types of vowels with a maximum and minimum duration

[8]Some vowels occur twice in the figure 7 and 8, the first vowel is characterized by the opened syllable structure and the second vowel is occurred in the closed syllable structure in the Khmer language.

classified by long and short vowels. Figure 8 shows the diphthongs of standard Khmer vowels with both long and short diphthongs. 10 long diphthongs and three short diphthongs are analyzed for the appropriate duration. The mean duration values may be sufficient to measure Khmer's vowel duration's phonological significance because of the considerable spread of vowel duration within the short and long vowel categories.

General Discussion and Conclusion

The measurement of modern Khmer vowels frequencies and durations has been the aim of this work. The first experiment on the phonetics of the standard Khmer vowel system was concerned with monophthongs. Ten long monophthongs and 11 short monophthongs were recorded, stored, and analyzed based on acoustic-phonetic characteristics. However, there were two common problems in monophthong measurement. First, the individual speakers differ in whether or not an increase in speech rate results in an increase in gestural overlap due to their employing different gestural implementations of the same cluster type (Tjaden & Weismer, 1998). This cluster type assumes the timing between the gestures that adapt the slow and fast speech. Another possibility is that speakers try to shorten the duration of the vowel while maintaining the relative timing. The issues are the syllabic closure structure of both long and short monophthongs completely changed the vowel duration, making it shorter than the opened syllabic structure. The long monophthong /i: / in the word ទី /ti: / (“place”) of 0.25 seconds is longer than /i:/ in the word ជីក /ci:c/ (to dig) of only 0.9 seconds. This shortening of duration was similar to the short monophthong /i/ in the word កាពិ/kaʔpi/ (Khmer fermented paste) that has a duration of only 0.9 seconds.

The ten long diphthongs and three short diphthongs are classified according to what was expected from previous studies because the presentation of vowel frequencies, F1 and F2, categorized these diphthongs as the variations of speech. The long diphthongs /iɜ/ as in ទា /tiɜ/ (duck) and ទៀត /tiɜt/ (again) are completely different in the pronunciation of Khmer native speakers. Frequency measurement, for example, of /iɜ/; ទា /tiɜ/ was 354 Hz and /iɜ/; ទៀត /tiɜt/ was 374 Hz. There is, however, differentiation of vowel duration between ទា /tiɜ/ and ទៀត /tiɜt/, 0.27 seconds, and 0.12 seconds. In some cases, there are differences in such words as ទារ ទៀត. Standard Khmer has two vowel distinctions /tiɜ/ and /tiət/, but in the Phnom Penh dialect, there is only the diphthong /tiɜ/ /tiɜt/ and the vowel contrast is identified in the standard Khmer vowel system. Also, there are /eː / and /ɛe/ in the Standard Khmer vowel system; in the Phnom Penh dialect, there is no difference between these two vowels; there is only one /eː/as in the words កើរ /keː/ and កែ /keː/.

Even though an instrumental phonetic analysis of Khmer dialects spoken in the Surin, Thailand (Wayland, 1998), and in PP dialect (Kirby, 2014) are the preliminary analysis that the present author should adapt; the problem that arose was the centralization of the open mid-vowel [aː] and open mid-vowel [ɑː] in the open syllable structure. Also, vowel length may be debatable in this case. Our audio files of [aː, ɑː] indicate that in the context of the open syllable, our speakers tended to lengthen the vowel nucleus. However, they are distinct in the close syllable. We suggest that the closed syllable structure, both long and short monophthong counterparts, could play a critical role in the distinction of the Khmer vowel system.

In conclusion, the Khmer vowel system is traditionally separated into two series (a and b) and registers (first and second). In Phnom Penh's long and short vowels, the first register vowels are lower and more open than the second register vowels. Moreover, the first register vowels are also diphthongized in Phnom Penh, respectively, similar to the BB vowels reported by Ratree Wayland (1998). However, the short vowels, for /o/, /ɔ/, /ɑ/, and /a/, are more centralized than the long vowels. Even though, in general, the Phnom Penh vowel system is a canonical form of the standard Khmer vowel system, some different structures and variations exist both in phonology and in phonetics.

Author Biographies

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