Registrogenesis in Khmer: A phonetic account

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1. Introduction

One of the outstanding problems in the history of Khmer phonology concerns the existence and development of 'register' or 'phonation types' (i.e. breathy versus clear voice) in the language. Few linguists have treated this question and proposed to reconstruct stages of development of both Khmer vowels and consonants in the past. However, since Khmer is the only member of the Khmeric branch of Austroasiatic (e.g. Thomas and Headley 1970, Diffloth 1974, Huffman 1976a) with no close relative, the traditional reconstruction approach is impossible. Thus, reconstruction was "primarily based on orthography, and on examination of orthographic developments as revealed in texts dating back to the 7th century" (Huffman 1978b, p1). However, as pointed out by Diffloth (1990), even though reliance on spelling conventions has been proven very fruitful in the studies of Southeast Asian linguistics, this practice is not without some drawbacks. He cautions the use of both modern Khmer spelling as well as Khmer inscriptional material as primary evidence in reconstructing the history of the Khmer language. He proposes instead, an approach in which the use of linguistic evidence and the comparative method is primary and the use of orthography is secondary (i.e. for confirmation or contradictions checking.)

2. What is register?

The term 'register' has been used in many different ways, with many different definitions by different groups of users including music and voice researchers, linguists and phoneticians. Among music and voice researchers the term 'register' or 'voice register' usually refers to pitch range or the rate of vocal fold vibration such that high pitch ranges belong to high register and low pitch ranges belong to low register.

In phonetics, 'register' is defined as the voice quality produced by a particular physiological setting of the larynx (e.g. soprano, tenor, falsetto). The term 'register' also includes types of phonation or modes of vibration of the vocal folds that a speaker can use in a controlled manner (e.g. creaky voice, whisper or murmur, etc.) (Crystal, 1992:331).

In sociolinguistics, on the other hand, 'register' refers to a variety of language defined according to its use in social situations (Crystal, 1992). For

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example, different varieties of language will be used by a speaker or groups of speakers in formal vs. informal, familiar vs. unfamiliar situations, and so on.

The definition of 'register' as pitch ranges defined by music and voice researchers has also been used by linguists to classify tonal languages. When discussing types of tonal languages, Pike (1948), for example, defines registers as contrastive level phonemes, as opposed to contour phonemes. Contrary to Sweet (1877) who pointed out the tendency of various languages to use one or the other, namely high or low, Pike asserts that a language can have two, three, or four registers as illustrated below:

Language A	*Language B*	*Language C*
High	high	high
		mid
	mid	norm
low	low	low

Thus, according to Pike, there are two types of tone languages: a register tone language and a contour tone language. A register tone language is a language that has a register-tone system, and a contour tone language is the one in which gliding tonemes are basic to the system (Pike, 1948:5-9).

'Register' as used by Henderson (1952) in her classic description of Khmer, however, is a phonological concept. It is a cover term referring not only to laryngeal activity but also to a cluster of activities in the vocal tract. She describes the characteristics of the two registers in the Khmer vowel system as follows:

> "The Cambodian 'registers' differ from tones in that pitch is not the primary relevant feature. The pitch ranges of the two registers may sometime overlap, though what I shall call the second register tends to be accompanied by lower pitch than first register. The characteristics of the first register are a 'normal' or 'head' voice quality, usually accompanied by a relatively high pitch. The characteristics of the second register are a deep rather breathy or 'sepulchral' voice, pronounced with lowering of the larynx, and frequently accompanied by a certain dilation of the nostrils. Pitch is usually lower than that of the first register in similar contexts. The register of the syllable is closely bound up with the vowel nucleus of that syllable, the two being mutually interdependent in the way that will be shown hereafter. In sentences, the word registers are modified according to intonation and by emotional factors. Register may be used, as in many other languages, to express emotion, and when this happens the emotional register may overlie the lexical register, much as in many tone languages intonation may overlie lexical tone." (Henderson, 1952:151-52).

Henderson also noted that vowels of the first register are generally more open in quality than those of the second register. However, "the different vowel 'color' inherent in the registers ensures that no vowel nucleus of the first register can ever have exactly the same quality as a vowel nucleus of the second register, no matter how alike their general description may be apart from the question of register" (p. 155).

Thus, for Henderson, the primary factor in 'register' is contrastive voice quality: 'normal' or 'head' vs. 'breathy' or 'sepulchral', while pitch and/or vowel quality are secondary and/or tertiary factors. In this sense, a register language may be defined as a language that has lexically contrastive voice quality with a complex combination of other phonetic features such as pitch and/or vowel quality, whereas a tone language has lexically contrastive pitch.

Even though the definition of 'register' suggested by Henderson (1952) was adopted by some South-East Asian linguists (e.g. Jacob 1968, Gregerson 1976, Theraphan 1991), other definitions, however, exist among other linguists. Diffloth (p.c., and Theraphan, 1991) for example, insists that a 'register' language should be specifically defined as a language that has contrastive phonation type or voice quality (i.e. breathy, clear, creaky etc.) ignoring any other phonetic features such as pitch that may accompany the phonation type contrast. As pointed out by Theraphan (1991), this definition of 'register' is both too specific and problematic since "both pitch and phonation type can be heard clearly in all register languages that I have come across" (Theraphan, 1991:44). Definitions of 'register' such as this and others have led to a great confusion concerning the typological classification of Khmer.

3. Is Khmer a register language?

Henderson (1952) was the first to analyze and describe the register elements in the standard Khmer vowel system. She described first register vowels as having a 'normal' or 'head' voice quality, usually accompanied by relatively high pitch, and second register vowels as having a 'deep rather breathy or 'sepulchral' voice quality, accompanied by relatively low pitch. She also stipulates that the second register vowels are produced with lowering of the larynx.

Dispensing with Henderson's contrastive pitch, Jacob (1968) stipulates that the first register vowels are pronounced with a clear, 'head' voice and a certain degree of tension and those of the second register are pronounced with a breathy, 'chest' voice and a comparatively relaxed utterance. However, Jacob also carefully adds that the distinction of voice quality in the utterance of the vowels and diphthongs of the two registers is only potential and is heard only occasionally in the speech of some speakers. Moreover, she rules out registral contrast in the three pairs if diphthongs which she transcribed (/iə/ìə/; / ɯə/ɯ̀ə/; /u:ə/ù:ə/) noting that the Khmer speakers themselves are confused about these diphthongs, not knowing to which register they belong and therefore not knowing which spelling to use.

Huffman (1978b) finds Henderson's description "phonetically very astute" (p.5). He pointed out that "while a native speaker might pronounce all second series vowels with one or another second register characteristics (i.e. with deep rather breathy voice, low pitch etc.) in an artificial reading pronunciation, in standard spoken Khmer all second register characteristics can be detected only in Henderson's /è, ò, ɛ̀, ɔ̀/; all other contrasts rely on absolute differences in position of articulation and/or diphthongization" (p.5). He also adds that in some dialects, such as Takeo, no second register characteristics are detected and that all contrasts between two sets of vowels are found in place of articulation and diphthongization. Thus, he proposes the term 'tense' (first register) and 'lax' (second register) as the cover terms for Henderson's two phonation types (Huffman, 1978b).

According to Huffman (1978b) the term 'register' should be reserved to refer to a language in which there is a complete dichotomy of phonation type throughout the vowel system. That is "in a 'register' language, every vowel can be unambiguously assigned to one or the other register" (Huffman, 1978b:2). By this criterion, he clearly stated that Khmer is certainly not a 'register' language and may never have been.

In 1978, at the Second International Conference on Austroasiatic Linguistics, Mysore, India, Henderson publicly stated that her observation of 'registers' in standard Khmer vowel systems was very unfortunate, agreeing with Huffman and other linguists working on the language that modern standard Khmer does not have registers (in the sense of phonation-type contrasts), and that the lone speaker mentioned in her paper, Mr. Vann Kheng, being "a student of philology and very interested in language from both the philosophic and aesthetic standpoints" was using an archaic reading pronunciation of Khmer, essentially a rendering of Khmer orthography (Diffloth, p.c.)

From a pedagogical as well as an analytical point of view, Jenner (1974) argued that the term 'register' should be retained in phonemic interpretations of standard Khmer but should be redefined. His 'register', however, refers not to phonation type, but rather to the articulatory position of the vowels. His 'low' register refers to Henderson's first register vowels which are usually lower in articulatory position than their second register counterparts, which he terms 'high register'. Moreover, his use of the grave accent to mark first register vowels is the reverse of Henderson's.

4. Was Khmer a register language?

Khmer is a language with a large vowel system: varying from 29-31 vowel nuclei from one researcher to the next. From the point of view of comparative Mon-Khmer, this is the consequence of a historical process of devoicing of consonants which has turned initial voiced stops /b, d, j, g/ into voiceless ones /p, t, c, k/. The older consonantal distinction has been transferred to the following vowels, causing the vowel system to split into two sub-systems, which has traditionally been termed 'a series' and 'ò series'

vowels by some linguists (e.g. Maspéro, 1915), and 'first register' and 'second register' or 'high' and 'low' register vowels by others (e.g. Huffman 1967, 1977; Jenner 1974b; Martin 1975).

There exists supporting evidence for the devoicing of initial stops hypothesis in Khmer. Huffman (1976b) examined 15 Austroasiatic languages and found that some languages, especially the Bahnaric, are 'conservative', retaining the original voiced and voiceless stop contrast with little or no effect on the vowels. Some Katuic languages, on the other hand, are 'transitional', retaining a tense-lax distinction in the initials (/p', t', c', k'/) versus /p, t, c, k/) with phonetic differentiation in the vowels. The third group of languages including the Monic and some Katuic languages are 'pure register' languages, with a complete merger of the stops and a complete register dichotomy in the vowels. The fourth group including Khmer is what he called 'restructured' languages, in which the phonetic and phonological merger of initial stops is complete, with the 'vowel' split reflected by a change in absolute articulatory position and /or diphthongization (Huffman, 1976b).

Since the merger of the original voiced and voiceless stops is complete in Khmer, previous attempts to reconstruct the history of Khmer vowels have relied heavily on Khmer orthography and its development in texts dating back to the VIIth century (Huffman, 1978b). For example, Pinnow (1957) based his reconstruction on the modern writing system. Jacob, on the other hand, based her reconstruction on Pre-Angkor (VII-VIIIth century) and Middle Khmer (XVIth century) texts (Jacob, 1960, 1963, 1965, 1976a, 1976b, 1976c, 1977). Jenner attempted to date the development of Khmer vowels by examining the rhyme patterns of Middle Khmer texts (Jenner 1974a, 1974b, 1975, 1976a, 1976b).

Up until recently, there was no internal phonological evidence for the existence of the 'breathy' and 'clear' voice contrast in the history of Khmer. In fact, Huffman (1978b) stated that "Khmer may never have been a register language" (p.2). The acoustic analysis of the vowel system of Chanthaburi Khmer by Wayland (1997), showing the distinction between 'breathy' and 'clear' voice suggested, however, that Khmer probably was a register language.

5. Registrogenesis in Khmer

It is generally accepted (Diffloth, 1990) that the main difference between Old and Modern Khmer phonology lies in the presence of a full set of four *voiced stop initials in old Khmer:

*b- *d- *j- *g-

contrasting with a corresponding set of *voiceless ones:

*p- *t- *c- *k-

Later, the *voiced stop initials were believed to have been devoiced and thus merged with the *voiceless initials shifting the contrasts to the

following vowels causing the vowel to split into two subsystems. The *voiceless initials then became voiced giving the impression that there was a "flip-flop" between *voiced and *voiceless initials in the history of Khmer. According to Diffloth (1990), such 'flip-flop' did not really occur. He contended that *voiceless initial (only **p* and **t*) first became voiced implosive /ɓ/ and /ɗ/ before they became voiced stops. These changes were captured by Diffloth in a scheme outlined below:

Stage 1:	*pV-	*tV-	*cV-	*kV-
	*bV-	*dV-	*jV-	*gV-
Stage 2:	*pV-	*tV̲-	*cV̲-	*kV-
	*bV̤-	*dV̤-	*jV̤-	*gV̤-
Stage 2.5	*ɓV-	*ɗV-	*cV-	*kV-
	*bV̤-	*dV̤-	*jV̤-	*gV̤-
Stage 3	*ɓV-	*ɗV-	*cV-	*kV-
	*pV̤-	*tV̤-	*cV̤-	*kV̤-
Stage 4	*ɓV-	*ɗV-	*cV-	*kV-
	*pV̤-	*tV̤-	*cV̤-	*kV̤-
Stage 5	*ɓV-	*ɗV-	*cV-	*kV-
	*pV-	*tV-	*cV-	*kV-

As shown in the scheme above, in stage 1 *voiced and *voiceless stops contrast in voicing, and there was not yet a register distinction in the vowels. In stage 2 *voiced and *voiceless stops still contrast in voicing, breathy phonation however appears redundantly in the vowel following *voiced stops and other *voiced initials, while clear phonation appears redundantly in vowels following *voiceless stops and other initials. Before the *voiced initials devoiced and merged with the *voiceless, Diffloth has proposed an intermediate stage (stage 2.5) in which *voiceless became *voiced implosives and contrasted with *voiced stops. Then later in stage 3, *voiced initial became voiceless contrasting now with the *implosives. Diffloth proposed this intermediate stage before *voiced initials lost their voicing but after the appearance of the clear and breathy phonation in the following vowels, for the following two reasons:

1. Vowels following the implosives have a clear phonation.
2. If **b-* and **d-* devoiced and merged with **p* and **t* then, it would be impossible for **t-* and **p-* to have an evolution distinct from **d-* and **b-* and an explanation would have to be provided for the newly evolved **d* and **b*.

While this reasoning appears to be reasonable, it forces Diffloth to propose that the *voiced implosives were contrasted with *voiced stop initials in the history of Khmer (Stage 2.5) which he admits is rather unusual. The voiced implosive and voiced plosive contrast, however, was reported for Uduk, a Niro-Saharan language (Ladefoged and Maddieson, 1996), implying that this contrast may be rare but not at all impossible.

After stage 3 in which the *voiced stops devoiced and merged with *voiceless stops, but the two phonation types remained in the vowels and became contrastive, the height of most vowels was affected differently by the

two distinct phonations (Stage 4). In general, the clear phonation vowels were lower and more diphthongized than the breathy phonation vowels. According to Diffloth, there is evidence in Khmer dialects that some vowels were affected earlier than others by the two phonations. Thus, he asserted that Stage 4 probably occupied a fairly long stretch of time and could be divided into several sub-stages. He also speculated that some of these sub-stages may have overlapped in actual time with Stage 3, or perhaps even with Stage 2. Finally, in Stage 5, phonation contrast disappeared, but the vowel qualities remained and became contrastive.

Diffloth's account of the evolution of Khmer vowels outlined above appears to be reasonable and may capture all the major changes that had occurred, however the order in which these changes took place deserves further discussion. Moreover, phonetic motivations for these changes were not clearly spelled out. For example, the emergence of breathy voice quality in vowels following voiced initials in Stage 2 was not phonetically motivated. Further more, the fact that changes occurred in the vowel without any accompanying changes in the initial consonants implied in Diffloth's scheme above also deserves a discussion.

According to Diffloth's account, at Stage 2, vowels following **p* retain their clear voice quality, but vowels following **b* take on a breathy quality with no change in the phonetic characteristics of either of the initials **b* and **p*. However, due to coarticulatory effect (a well-known characteristic of speech sound), a change in vowels may not be an isolated event and should be considered in relation to surrounding segments. The most relevant one in this case is the initial consonants. In sections to follow, we will try to provide a plausible phonetic account of registrogenesis in the Khmer vowel system. Crucial to the proposal is the interaction between initial consonants and the following vowels and the observations made by Huffman (1985) regarding the development of diphthongs in Khmer and two other Mon-Khmer languages.

According to Huffman (1976b), the 15 Mon-Khmer languages that he examined fall into five subgroups: conservative, transitional, register, restructured and tonal. Conservative languages are those that retain the original or proto voiced-voiceless contrast. These include some Bahnaric languages. The proto voiced-voiceless contrast becomes a tense-lax contrast with subphonemic register differentiation in the vowels after the stops, but not after the continuants. The third subgroup consists of "pure register" languages with complete merger of the stops and a complete register contrast in the vowels. A fourth subgroup which includes Khmer are called "restructured" languages. For this group, "there is a complete phonetic and phonological merger of initial stops, with the 'vowel split' reflected by change in absolute articulatory position and/or diphthongization. A fifth subgroup includes Vietnamese, a language in which the devoicing of the proto voiced consonants results in a doubling of the number of tone contrast" (Haudricourt 1954, Huffman 1977, cited in Huffman, 1985).

To illustrate his definition of "restructured" languages, Huffman juxtaposed the first and second register reflexes of the nine long vowels

implied by the Khmer writing system (as shown below) and found that "the 18 long vowels of Khmer can be analyzed totally in terms of diphthongization vs. non-diphthongization, or changed vs. unchanged" (Huffman, 1985, p.141).

2nd	ī	ii	ɨ̄	ɨɨ	ū	uu
1st		əi		əɨ		ou
2nd	ē	ee	ə̄	əə	ō	oo
1st		ɛe		aə		ao
2nd	ɛ̄	ɛɛ	ā	ia	ɔ̄	əɔ
1st		aɛ		aa		ɔɔ

After examining the distribution of monophthongs and diphthongs in two other "restructured" languages (i.e. a Bru dialect spoken in Ubol province, Thailand and Nge?, a Katuic language spoken in Saravan Province of Laos), he made the following observations regarding the process of diphthongization.

1. High lax vowels and low tense vowels tend to remain stable.
2. Tenseness produces lowered onsets in high vowels.
3. Laxness produces raised onset in low vowels.
4. Mid vowels may participate in either pattern, depending on the language.

These observations regarding the process of diphthongization provide a basis for the registrogenesis hypothesis in the Khmer vowel system. This proposal is outlined in the next section.

6. A phonetic account for registrogenesis in Khmer

Following the classic theory of the history of Khmer vowels, I assume a contrast between voiced and voiceless initials as the initial stage. Next, voiced stop initials become slack voice[1] causing the following vowels to become breathy. Voiceless initials become tense, fortis or more likely stiff voice[2] stops followed by vowels with clear voice quality. Evidence for this hypothesis comes from modern Javanese in which vowels following slack voice stops are breathy and vowels following tense stops are clear. Thus, at this stage, the contrast is between the slack/lenis and the stiff/fortis initial consonants, with a subphonemic distinction in breathy and clear voice quality in the following vowels.

Later, the distinction between slack voice and stiff voice initial consonants is weakened and the breathy and clear voice contrast in the vowel becomes more and more distinct. It is hypothesized that at this stage, in order to make breathy vowels become more distinct, the phonetic characteristics of slack voice stop initials must include a slow, gradual, delayed release to the following vowels. This results in the following breathy vowels with a

[1]See Ladefoged and Maddieson 1996 for a description of slack voice stops.

[2]See Ladefoged and Maddieson 1996 for a description of stiff voice stops.

relatively longer formant transition. Stiff voice initials, on the other hand, are characterized by a strong, emphatic, abrupt and imploded release thus enhancing the clear voice quality of the following vowels.

In the next stage, the formant transition from the release of the initial consonant to the following vowels is reanalyzed by listeners. Specifically, the transition is reanalyzed and incorporated as part of the following vowels causing the vowels to be heard as diphthongs. The formant transition from slack voice stop initials gives rise to a high onglide to the low central and back vowels, and the transition from the stiff voice initials gives rise to a low onglide to the following high, central and low front vowels.

Since the tongue position is already relatively higher among high vowels, the transition from the release of the initial slack voice to the following high vowels is not sufficiently prominent to produce a percept of a gliding onset. This may explain why high vowels following slack voice initials was not heard as diphthongs. The relative height of the onglides of the following low central and back vowels varies from language to language, however. For example, **da* 'duck' > [tea] in Battambang Khmer, but [tia] in modern standard Khmer spoken in Phnom Penh. This may depend articulatorily on the speed and the magnitude in which the tongue lowers during the transition from the initial stop to the following vowels. The faster and the smaller the magnitude of tongue lowering (thus relatively shorter formant transition), the higher the quality of the onglide.

Later, due to its strong, abrupt, imploded release, stiff **p* becomes voiced implosive /ɓ/ while the following vowels remain clear, and slack voice **b̥* becomes /p/ while breathy voiced quality remains in the following vowels. Thus, at this stage the contrast is between implosive /ɓ/ and /p/ with accompanying clear and breathy voice quality. Finally, breathy voice disappeared, but vowel quality remained.

Thus, according to this hypothesis, the evolution of Khmer vowels systems can be captured stage by stage as shown below. It is important to note, however, that these stages are merely designed to capture all of the changes that occurred and do not suggest that there was no overlap among these changes across the whole vowel system (as will be discussed below). In other words, these stage-like sequences represent a continuum in which the changes progress.

Stage 1	*pV	*tV	*cV	*kV
	*bV	*dV	*jV	*gV
Stage 2	*pV̲	*tV̲	*cV̲	*kV̲
	*b̥V̤	*dV̤	*jV̤	*gV̤
Stage 3	*p^{v}V̲	*t^{v}V̲	*c^{v}V̲	*k^{v}V̲
	*b̥^{v}V̤	*d^{v}V̤	*j^{v}V̤	*g^{v}V̤
Stage 4	*ɓ^{v}V̲	*d^{v}V̲	*c^{v}V̲	*k^{v}V̲
	*p^{v}V̤	*t^{v}V̤	*c^{v}V̤	*k^{v}V̤
Stage5	*ɓVV	*dVV	*cVV	*kVV
	*pVV	*tVV	*cVV	*kVV

Stage 1: A contrast between *voiced-voiceless initials.
Stage 2: *Voiced-voiceless initials become *slack vs. stiff voice initials and gradually become contrastive. Breathy and clear voice quality occur redundantly in the following vowels.
Stage 3: Formant transitions from initial *slack vs. stiff voice to some of the following vowels are reanalyzed as part of the following vowels causing the vowels to become diphthongized. *Slack vs. stiff voice remains contrastive, and breathy vs. clear voice quality in the following vowels remain redundantly.
Stage4: Stiff **p* gradually becomes voiced implosive and slack **b̥* gradually becomes voiceless /p/. The following vowels remain the same as in Stage 3.
Stage 5: Breathy voice quality in the following vowels disappears, but the vowel quality remains.

Thus, according to the above account:

1. There is no stage at which implosive /ɓ/ and voiced /b/ were contrastive.
2. Breathy voiced quality is induced by a change in phonetic characteristics of initial consonants.
3. Gliding onsets of diphthongs in second register vowels are explained in terms of perceptual reanalysis of the formant transition between the release of the two kinds of stops (slack/stiff voice) to the following vowels.

As already observed by Diffloth (1990), each stage of the evolution of Khmer vowels may occupy a fairly long stretch of time and some stages may have overlapped in actual time. The emergence of the breathy and clear vowels following the slack and stiff voice stops in Stage 2 is a good example. It is conceivable that not all vowels following slack voice stops become breathy at the same time and to the same degree. A production of breathy voice requires that the vocal folds are relatively lax and far apart. Thus, all else being equal, high vowels with relatively taut vocal folds will sound less breathy than low vowels.

Initial consonants may also play a role contributing to degrees of breathiness in the following vowels. Vowels following consonants with a constriction toward the front of the oral cavity (e.g. bilabial, dental and alveolar) yielding relatively greater supra-glottal area will sound more breathy than vowels following consonants with a constriction toward the back of the oral cavity (e.g. palatal and velar), thus yielding a relatively smaller supra-glottal area. In other words, breathiness in the following vowels will be progressively more difficult to produce and maintain as the preceding consonants' place of articulation moves progressively back toward the glottis. This is because, all else being equal, relatively larger supra-glottal area will result in relatively lower supra-glottal pressure, and the greater the difference between supra-glottal and subglottal pressure, the greater the degree of perceived breathiness. Therefore, it is possible that different vowels become breathy at different times and to varying degrees in Stage 2. Similarly, different

vowels will cease to be breathy at different times and at a different rate in Stage 4.

The manner of articulation of initial consonants may also contribute to degrees of breathiness. This hypothesis is suggested by the observation made by Huffman (1985) that in transitional languages, the subphonemic register distinction in the vowels was found only after stops, but not continuants. Unlike continuants, the possibility of a complete closure and delayed and gradual release of the constriction among stop consonants helps lengthen and thus enhance the perceived degree of breathiness of the following vowels. Since the production of a continuant does not include a complete closure, breathiness in vowels following continuants may sound less breathy and may be maintained only for a relatively short period of time. This may explain why breathiness in vowels following continuants will cease to exist relatively sooner than breathiness in vowels following stop consonants.

The reanalysis of the formant transition from initial stops as part of the following vowels (diphthongization process) is also expected to vary from vowel to vowel. In other words, not all vowels of Khmer became diphthongized at the same time. This is due, in part, to the interaction between the formant frequencies [first and second formants (F1, F2)] of the transition and the F1 and F2 of the following vowels. For example, we hypothesized that slack voice stops in Stage 2 are produced with a relatively gradual or delayed release resulting in a relatively long formant transition with low F1 and high F2 values. This low F1 and high F2 formant transition was then reanalyzed as an onglide to the following vowel. Due to a relatively greater difference between the F1 and F2 values of the transition and the F1 and F2 values of the following central and low back vowels, the onglide is perceptually more salient among these vowels (/a/, /ɔ/). The relatively smaller difference between the F1 and F2 values of the transition and the F1 and F2 values of the following high vowels, on the other hand, was not perceptually salient for an onglide to be perceived.

The abrupt and imploded release of initial stiff voice stops, on the other hand, results in a transition with relatively lower F1 (when compared to that of the following vowels). This transition was reinterpreted as a relatively low onglide to the following vowel. The magnitude of the difference between the F1 and F2 values of the transition and the following vowels as well as the vowel length may also contribute to degree of perceptual saliency of the formant transition. The greater the difference in the F1 and F2 dimension, the more salient the transition and the more likely and quickly that it will be reanalyzed as part of the following vowels. On the other hand, the shorter the vowel, the shorter the transition, thus the less likely that it will be heard and reanalyzed. The interaction between these two dimensions (F1, F2 difference and length) will determine the rate in which vowels following the initial stiff voice stops will become diphthongized. This may be the reason why short /a/ in Chanthaburi is resistant to diphthongization (see Wayland & Jongman, 2001), as in the following examples:

[kạt] 'he, she (third person singular pronoun)'
[mạn] 'a hen, chicken'

Eventually, the */ạ/, however, diphthongized as found in */man/ > [mⁱən] 'hen' in Battambang Khmer. The [ⁱ] onglide results from a gradual delayed release of the initial /m/.

7. Conclusion and suggestions for further research

Khmer is a language with a large vowel system. The classic theory involves positing an initial voiced-voiceless stop contrast in the original or proto forms of Mon-Khmer. The voiced series /b, d, j, g/ then merged with the voiceless set /p, t, c, k/ doubling the number of vowel contrasts. Several researchers have proposed to reconstruct the evolution of Khmer mainly by examining orthographic evidence. Absent has been a phonetic account of the evolution of the Khmer vowel system, especially in regards to the emergence of the register contrast, that is, the contrast between the breathy and clear voice quality in the history of Khmer vowels. The goal of this study is to fill this gap in the literature. Even though other changes also occurred in the history of Khmer vowels, this study concerns only the registrogenesis in the Khmer vowel system.

This study attempts to provide a phonetic account for the emergence as well as the development of the two registers (breathy and clear) in Khmer. According to this hypothesis, the original voiced vs. voiceless stop contrast first become a slack (lenis or lax) vs. stiff (fortis or tense) stops, giving rise to breathy vs. clear vowel quality in the following vowels. Even though the exact phonetic characteristics of these stops are not known, it is hypothesized that these characteristics must include a relatively slack, gradual and delayed release, resulting in low F1 and high F2 formant transition for the slack voice stops, and an emphatic, abrupt and imploded-like release, resulting in a relatively lower F1 and F2 formant transition for the stiff voice stops. The formant transitions from the stops to the following vowels were then reinterpreted and were heard as part of the following vowels causing the following vowels to be heard as diphthongs. The interaction between the formant transition and the following vowels was posited to account for which of the following vowels became diphthongs and which did not. As the final stage, the breathy vs. clear voice contrast disappeared from the Khmer vowel system, but the vowel quality remained, as seen in the vowel systems of modern dialects of Khmer spoken in Phnom Penh and other provinces.

Crucial to the present hypothesis was the existence of breathy and clear voice in the vowel system of Chanthaburi Khmer and insights gained from the observations made by Huffman (1985) pertaining to the process of diphthongization. An interaction between initial consonants and the following vowels is also crucial to the proposed hypothesis. The motivation for the emergence of a breathy quality (contrasting with the clear voice quality) in the vowels following the original *voiced stops, for example is thought to be due to this interaction. Thus this hypothesis:

1. Explicitly accounts for the emergence of the breathy vs. clear voice quality in the history of the Khmer vowel system, as attested in the vowel system of Chanthaburi Khmer.
2. Avoids positing the rare albeit possible contrast between the voiced plosive and voiced implosives in the history of Khmer vowels (common in Bahnaric).
3. Explicitly accounts for the diphthongization process in the history of Khmer.
4. Provides possible accounts for the overlaps among stages of the evolution of Khmer.

Finally, several hypotheses put forward in this current theory of the history of Khmer vowels deserve further investigation. The reanalysis of the formant transition from the slack voice vs. the stiff voice stop initials, for example, should be investigated empirically. The claim regarding varying degrees of breathiness in high and low vowels, between vowels following obstruents and sonorants as well as between vowels following front and back consonants also deserves further attention. Moreover, whether or not this theory can be extended to account for registrogenesis in other languages should also be explored.

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