1 *A phonetic study of Eastern Cham register*[1]

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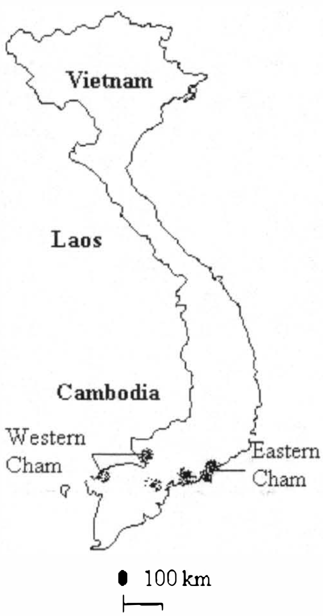
Eastern Cham (also Phan Rang Cham) is an Austronesian language spoken in the provinces of Ninh Thuận and Bình Thuận on the south-central coast of Vietnam. As Chamic speakers have been in contact with Mon-Khmer languages over the past two millennia, it has been claimed that contact has played a major role in the transformation of Cham from a typical Austronesian to a typologically Mon-Khmer language (Thurgood, 1996, Thurgood, 1999, Thurgood, 2002a). Nowadays, the Mon-Khmer language that has the strongest impact on Cham is Vietnamese: after the fall of the kingdom of Champa to the Vietnamese in 1471, the Cham have gradually become a small minority even in the Cham heartland[2] and have lived under the ever-growing sociopolitical dominance of the Vietnamese. For this reason, almost all, if not all, Eastern Cham speakers are bilingual, which significantly affects the structure of their language (Thurgood, 1996, Thurgood, 1999).



A feature of Eastern Cham that is often considered to be contact-induced is register. Registers are complexes of phonetic features such as pitch, voice quality and vowel quality that often accompany vowels in Mainland Southeast Asian languages (Henderson, 1952, Matisoff, 1973). It is well-established that Eastern Cham has two such registers, although their Mon-Khmer origin is difficult to prove (Blood, 1967, Bùi, 1996, Moussay, 1971). More controversially, it has been hypothesized in the past twenty years that these two registers are rapidly evolving into a tonal system under the influence of Vietnamese (Hoàng, 1987, Phú et al., 1992,

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[2] Currently, there are 40,000 or 50,000 Cham out of 1,300,000 people in Ninh Thuận and Bình Thuận provinces (Phan et al., 1991).

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Thurgood, 1996, Thurgood, 1999). This case of contact-induced sound change can be investigated from three angles: phonetics, phonology and sociolinguistics. In this paper, I look at the phonetic evidence about Eastern Cham registers. I argue that while pitch plays a central role in the Eastern Cham register contrast, registers are still relatively conservative and are not evolving into a full-fledged tone system. A study of sociolinguistic variation in the realization of register and of its phonological status is beyond the scope of this paper, but is addressed in Brunelle (2005a).

In Section I, I discuss the diachronic developments that have led to the formation of Cham register and review the arguments that have been proposed in favor of a tonal analysis of Eastern Cham. In Section 2, I describe the realization of coda consonants and register allophony and show that Eastern Cham cannot be treated as a full-fledged tone language. Finally, in Section 3, I provide the reader with an acoustic description of Eastern Cham register and look at the perception of register by native speakers. I argue that despite the fact that the registers of Eastern Cham "look tonal", there is little phonetic evidence that they have really evolved into tones.

1. Historical developments and previous work

While Ancient Cham had contrastive voicing in onset stops (still reflected in writing), Modern Cham dialects have neutralized this voicing contrast in favor of the voiceless series (except in preglottalized stops). The role of voicing was taken over by a register distinction on the vowels following stops: while vowels following a former voiced stop took on a breathy quality and a low pitch, all other vowels kept a mid-range pitch and a modal voice. There is also evidence that before the split between Eastern and Western Cham, vowel quality might have played a role in the system : in Western Cham, high register vowels are typically realized as more open than low register vowels (Edmondson and Gregerson, 1993, Headley, 1991). We can hypothesize that the original Cham register system had the following features:

(1) Phonetic properties of registers

***Voiceless obstruents, sonorants, implosives >**	***Voiced stops >**
High Register	**Low register**
High pitch	Low pitch
Modal voice	Breathy voice
Lower vowels?	Higher vowels?

It is difficult to date the formation of register, but two 19th century sources list Cham words with voiced stops. The first is a short wordlist compiled by John Crawfurd during a short stay in Vietnam (Thurgood, 2002b). As pointed out by Thurgood, Crawfurd's list is not necessarily reliable, but a later source, Etienne Aymonier's *Grammaire de la langue chame,* contains further evidence that the merger was not complete in the 19th century (Aymonier, 1889). In his grammar, Aymonier does not mention that the voiced onsets of Classical Cham are devoiced in speech, despite a thorough examination of the production of every letter of the Cham script. The only reference to melody is on page 34:

> " Enfin, nous terminerons cette étude de l'alphabet usuel en faisant remarquer la forme particulière, peu usuelle pour ainsi dire, des quatre consonnes aspirées gha, jha, dha, bha. Les mots chames qui les emploient sont assez rares. Au Cambodge, les étudiants lisant l'alphabet chame laissent tomber la voix sensiblement sur ces quatres lettres, comme dans les mots annamites affectés de l'accent grave."
>
> "*Finally, we will conclude this study of the common script by noticing the peculiar, unusual, form of the four aspirated consonants gha, jha, dha, bha. Cham words making use of them are rather rare. In Cambodia, students reading the Cham alphabet let their voice fall on these four letters, as in the Annamese words marked with the grave accent.*" (my translation)

In this passage, Aymonier points out that Cambodian Cham speakers pronounce voiced aspirated stops with an intonation reminiscent of the low level tone of Vietnamese. However, there is no mention of devoicing, of a special intonation on plain voiced stops or even of the pronunciation of Eastern Cham speakers, with whom Aymonier did most of his work. This could be interpreted as evidence that the voiced stops of Eastern Cham were not devoiced when Aymonier wrote his grammar and that the characteristic low pitch of the low register was either not clearly audible after unaspirated stops or still masked by the voicing of the onset.

If this interpretation of Aymonier is correct, voicing neutralization in onsets and the resulting registrogenesis could hardly be due to contact. At the time when Aymonier wrote his grammar, Vietnamese, a language that does not have typical Mon-Khmer register, was the only language in contact with Eastern Cham. Some register languages belonging to the Bahnaric branch of Mon-Khmer were spoken in neighboring provinces, but contacts with these languages must have been episodic at best, since the Vietnamese forbade contacts between the Cham and other minority groups after two multiethnic revolts in the 1830's (Po, 1987). Another possibility is that Aymonier and Crawfurd's descriptions are simply inaccurate and that register developed much before the arrival of the French in the late 19th century. This is suggested by the presence of registers in all coastal Chamic languages. Since the common ancestor of the Coastal languages presumably split a few centuries ago, the preservation of the voicing contrast in 19th-century Eastern Cham entails that Coastal languages developed register independently, a rather uneconomical scenario.

In any case, the first modern descriptions of Eastern Cham by Christian missionaries are clear: contrastive voicing had been lost by the 1960's (Blood, 1967, Moussay, 1971)[3]. These sources also emphasize the fact that the two registers of Eastern Cham have different allophonic realizations conditioned by their codas, although the descriptions of these realizations conflict to some extant. Moussay, for example, lists four allophones (p. XIII):

- a level "tone" on vowels preceded by voiceless onsets and followed by all codas but the glottal stop
- a low tone (*ton grave*) on vowels preceded by voiced onsets and followed by all codas but the glottal stop
- a rising tone (*ton quittant*) on vowels preceded by voiceless onsets and followed by a glottal stop

[3] Although this is contradicted by Mr. Lưu Quý Tân, in a personal communication to André Haudricourt (Haudricourt, 1972).

- a falling tone on vowels preceded by voiced onsets and followed by a glottal stop

In contrast, Blood treats the two registers as two pitch "phonemes", but states that "before final stops and the *h* the register of non-low pitch is higher than in syllables ending in the other consonants or silence." (p.29). Despite their different descriptions or register allophony, Moussay and Blood do agree that codas have an allophonic effect on the pitch of the two registers.

Recently, a few scholars have published work in which they treat the coda-conditioned allophones as phonemic or incipiently contrastive (Hoàng, 1987, Hoàng, 1989, Phú et al., 1992). A crucial tenet of these hypotheses is that some final consonants (especially laryngeals) are weakened or dropped, leading to a reinterpretation of the coda contrast as a pitch contrast. While it is uncontroversial that some coda stops have undergone reduction (-p > -wʔ, c > jʔ), other alleged consonantal changes are more speculative. For example, the claim that "... the stops [-p, -t, -k] have fallen together as glottal stop and *h* has been lost altogether" (Phú et al., 1992) is not borne out by the findings presented in Section 2.

Before discussing my own findings about the registers and tones of Eastern Cham, a summary of the only experimental study of these issues to date is in order. Phú et al. (1992) recorded three minimal pairs from one male native speaker of Eastern Cham (following Moussay, I use the subscript dot to mark the low register)[4]:

(2)	High register		Low register	
	/pa/	'where, at'	/p̣a/	'to carry'
	/paʔ/	'four'	/p̣aʔ/	'to walk'
	/păʔ/	'straight'	/p̣ăʔ/	'to tap'

The authors then measured and compared the f0 curves (pitch) of the three pairs. As expected, vowel pitch is consistently lower following /p̣/. The low register also has at least two realizations: a rising pitch before the glottal stop and a low level pitch in open syllable. However, no such split was found in the high register. In that register, the open syllables and the syllables closed by a glottal stop have similar shapes and height. Phú et al. (1992)'s results therefore suggest that Eastern Cham has at least three surface register allophones.

Based on these empirical results, the authors go a step further and propose that coda glottal stops could have become "part of the internal stuff of a given tone" (p.41). The glottal stop would have lost its status of coda consonant to become a tonal element, a part of a glottalized tone. This amounts to saying that the low register would have split into two distinctive tones. In other words, Phú et al. put forward the possibility that Eastern Cham is already a three-tone language. This is to my knowledge the only explicit and refutable scenario for the development of a complex tone system in Eastern Cham. Unfortunately, despite the fact that the authors are careful not to jump to conclusions, their reasons for treating the glottal stop as a tonal property remain unclear.

[4] Besides the fact that /pa/ means 'where' only as an exclamative, which could affect its pitch, there is another problem with the wordlist: according to the first author and subject of the experiment, the word /p̣aʔ/ 'to take a walk' is his "modern rendition" of the Ancient Cham word /kalip̣aʔ/ and is not normally used in speech. Therefore, his pronunciation could be relatively artificial.

Have registers really evolved into tones or are they still a property of onsets? In order to answer this question, I will first look at the phonology and phonetics of registers in Section 2. The realization of codas and their effect on register will then be explored in Section 3.

2. Codas and Tones

In this section, I investigate the status of coda consonants and I describe their effect on the phonetic realization of registers. More specifically, I show that coda consonants condition register allophony, but that this allophony has not been reinterpreted as contrastive tone.

Coda stop weakening is not a recent phenomenon. In the late 19th century, Aymonier already noted that the final graphemes *-p*, *-c* and *-k* were being reduced (Aymonier, 1889):

> "k se prononce faiblement à la fin de beaucoup de mots dont il rend la prononciation brève et saccadée." (p. 32)
> *"k is weakly pronounced at the end of many words and makes their pronunciation short and abrupt." (my translation)*
> "Le p final se reconnaît facilement à l'oreille dans certains mots tels que gâp, mutuel, mais il est bien difficile à un Européen de saisir cette consonne dans d'autres mots tel que hudiêp, femme, vivant." (p.32)
> *"Final p is easily recognizable in some words like gâp, mutual, but it is difficult to perceive it for a European in other words like hudiêp, wife, alive." (my translation)*
> "En somme, à la fin des mots, les consonnes k et p ne se prononcent presque pas et donnent au mot un arrêt un peu brusque de la voix, où une oreille fine et exercée peut seule reconnaître la nature de la consonne." (p. 32)
> *"In short, at the end of words, the consonants k and p are almost not pronounced and give to the word a rather abrupt interruption of the voice, where only a fine-tuned and trained ear can recognize the nature of the consonant." (my translation)*
> "Le ch final du chame est prononcé à peu près comme i ou y dans la plupart des mots. Exemples : lach, dire; ach, incurie; baganrach, grand plateau des sacrifices, sont prononcés laï ou lay ou ay, baganray, etc." (p.33)
> *"The final ch of Cham is pronounced roughly like i or y in most words. Examples: lach, to say; ach, caresslessness; baganrach, large sacrificial tray, are pronounced laï or lay or ay, baganray, etc." (my translation)*

Although they are somewhat impressionistic, these descriptions totally agree with the type of coda reduction that is found today. The first passage describes the modern reflex of written Cham *-k* as a glottal stop, which is still the normal realization of this coda today. The other passages also reflect a state of affair identical to what is found in the modern language: stops are often reduced, especially in high-frequency words, but they are never deleted.

2.1. Experiment

An acoustic study of final consonants and of their effects on vowels was carried out to determine the type of changes that final consonants are really undergoing and to evaluate the claim that the loss or neutralization of final consonants has caused the development of contrastive tone.

2.1.1. Methods

A wordlist designed to test the phonetic realization of register and the effect of codas on pitch was recorded with 43 native speakers of Eastern Cham. The wordlist was composed of all possible monosyllabic words with the vowels /a:/ and /ă/[5], starting with the labial onsets /p, pʰ, b, m, w, ʔw/ and combined with all the possible Written Cham codas <p, t, c, ʔ, m, n, ŋ, j, w, h, 0> (Written Cham is transcribed in brackets < >). All possible combinations of these factors were computed, resulting in a list of 252 possible words. I then went through this list with Phú Văn Hẳn, a Cham linguist, and excluded meaningless monosyllables. A few words with dental sonorant onsets were then added to make sure that enough sonorant-initial words would be included in the wordlist, yielding a list composed of 99 real words.

The wordlist was originally designed to be read. However, since very few speakers could read the Cham script fluently, I quickly abandoned the initial idea of working with a wordlist written in this script. To further complicate things, many Cham are hostile to romanization (Blood, 1977, Blood, 1980) and many speakers simply refused to try to read a romanized wordlist. For these reasons, only three speakers read the wordlist. All other speakers were given the target words in Vietnamese and asked to translate them in Cham. The speakers were then instructed to repeat them at least three times in a frame sentence[6]. Whenever speakers were not familiar with a word, it was not recorded[7]. All recordings were made with a Marantz PMD-680 card recorder and an AKG C5900 microphone.

The frame sentence used is given below:

(3) /t̥ahlăʔ dom akhăn ____ ka ɲu păŋ/
I say word ____ for he hear
"I say the word ____ for him"

Minor variations in the frame sentence were allowed (/kăw/ 'informal I' instead of /t̥ahlăʔ/ 'formal I', /aj/ 'brother' instead of /ɲu/ 'he'). Further, most speakers consistently realized /t̥ahlăʔ/ and /akhăn/ as /hl̥ăʔ/ and /khăn/, their colloquial monosyllabic correspondents. A majority of speakers were comfortable with the frame sentence, but a few of them had to be trained for a few minutes before the recording session.

Some target words were realized as sesquisyllables by a few speakers. I cannot discuss this question in detail here, but colloquial Eastern Cham has become almost entirely monosyllabic, except in very formal speech (Brunelle, 2005a, Brunelle, *to appear*). For the purpose of this experiment, whenever a word was realized as a sesqui/polysyllable, only the final stressed syllable was measured.

Since the wordlist just described only includes words with the vowels /a:/ and /ă/, I also recorded a second wordlist consisting of 38 words including all possible other vowels combined with 5 codas that have been claimed to be reduced or dropped by Phú et al. (1992). It is much less systematic than the first wordlist in that it does not exhaust all

[5] Note that short /ă/ is often allophonically realized as /ɛ̆/ before /-j/ and /-t/ and as /ɔ̆/ before /-w/.

[6] With the first three speakers, I recorded the entire wordlist three times, consecutively. However, as this procedure took too long, I made the decision of recording each word three times with the 40 remaining speakers.

[7] Some lexical items vary from village to village. Learned and semi-learned words are not widely known.

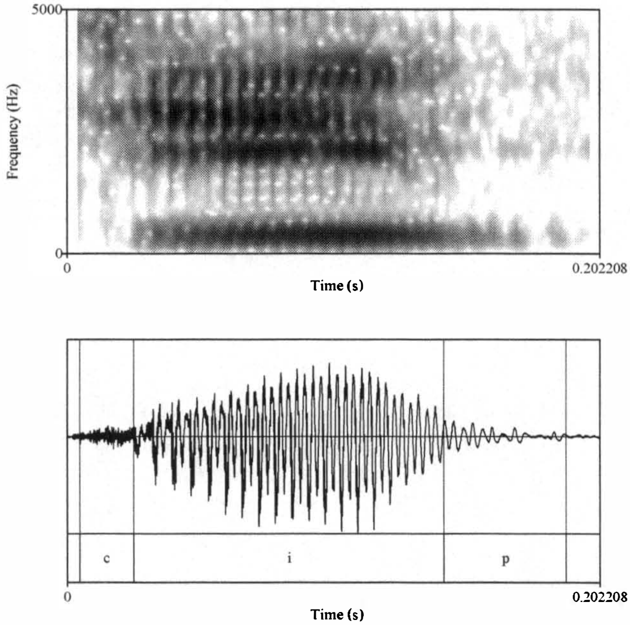
possible rimes and onsets, but it was included for comparative purposes. The target words of the second wordlist were recorded in the same frame sentence as the first wordlist with 14 speakers and in isolation with 26 speakers who showed less patience (these speakers are a subset of the speakers who read the first wordlist). The recording sessions were conducted identically.

The determination of the place and manner of articulation of the various codas was done through a visual and auditory inspection of the waveforms and spectrograms of all target words with the acoustic software *Praat 4.2* (Boersma and Weenink). Coda stops were categorized as either fully realized, debuccalized to a glide + glottal stop sequence, reduced to a simple glottal stop or deleted. Coda <h> was categorized as either fully realized or missing.

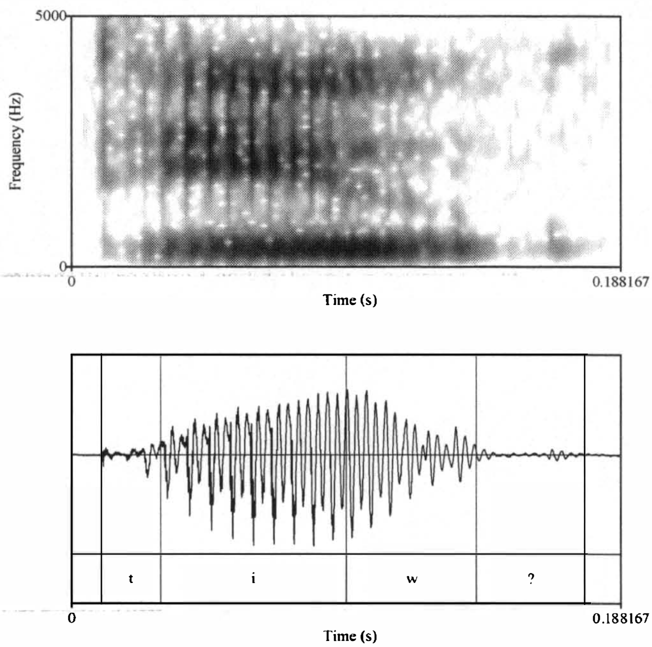
2.1.2. Results

Overall, the results suggest that there is relatively little variation in the realization of written Cham codas in modern Eastern Cham. Individual speakers always realize the coda of a specific word consistently. There is a limited amount of variation across speakers, but it is typically restricted to low frequency words. Coda stops can be either realized as unreleased stops or be debuccalized to a glide followed by a glottal constriction. On the other hand, final laryngeals are almost never deleted except in a few function words.

In order to illustrate what is meant by full realization and debuccalization of coda stops, a short illustration and discussion of the behavior of coda /-p/ follows. This coda was chosen because it is the only one that has two robust variants. Spectrograms of other codas are given in Brunelle (2005a). The modern reflexes of final <-p> are the full stop /-p/ (Figure 4) and the labio-velar glide followed by a glottal stop /-wʔ/ (Figure 5). The word /c̥ip/ 'clear, understandable' is realized with an unreleased [p]. The vowel preceding it has stable formants that are interrupted relatively abruptly by the closure of the coda stop. By contrast, at the end of the vowel of /t̥ĭwʔ/ 'wife', vocal fold vibrations are much more irregular and F2 gradually goes down as the high front vowels turns into a labio-velar glide. Note that in (4), there are still vocal fold vibrations during the [-p], indicating partial voicing. This weak voicing is often visible on waveforms and spectrograms, but is rarely audible.



(4) Waveform and spectrogram of /c̥ip/ pronounced by a man born in 1966



(5) Waveform and spectrogram of /t̥̆iwʔ/ pronounced by a man born in 1966

As is the case for the words /c̥ip/ and /t̥iwʔ/, specific lexical items can be realized with either [-p] or [-wʔ], but do not vary. Learned words typically have a [-p], while common words tends to have the debuccalized form. The realization of other codas in Eastern Cham is even less variable as we can see from the modern realizations of Written Cham codas after /a:/ and /ă/ given in Table (6). It gives the realization of each stop (including the glottal stop) after various vowels for 43 speakers. The number of tokens should in theory equal the number of words multiplied by three repetitions and 43 speakers. However, some words were unknown to some speakers and were not recorded, and some tokens had to be excluded because of background noise or other recording problems. Therefore, the total is typically below the possible maximum number of tokens.

(6) Realization of written Cham codas after /a:/ and /ă/ (43 speakers)

Written Coda	<p> (3 words)	<t> (8 words)	<c> (5 words)	<ʔ> (12 words)	<h> (11 words)
Total	200	848	0	1376	1398
Debuccalized	0	0	611 [-jʔ]	[redacted]	
Dropped	0	0	0	11	0
% Dropped	*0%*	*0%*	*0%*	*0,799%*	*0%*

First, coda <p> is always realized as a full stop, because the wordlist was not originally designed to test the ways in which codas are reduced, but the effect of codas on the realization of registers. The few items ending in <p> that were included in this list are learned words, which explains the lack of debuccalization of /-p/. In colloquial speech, there are numerous instances of debuccalization of /-p/ after /a:/ and /ă/ (one of them is included in the second wordlist below). Other consonants have a single surface realization: <t> is always realized as [-t], <c> is always surfaces as [-jʔ] and <h> is always fully pronounced. Final <ʔ> seems to be occasionally missing, but since this happens in less than 1% of the tokens, this could hardly be used as evidence of the loss of coda glottal stops.

The realization of coda stops after other vowels is similar, although the idiosyncratic behavior of some words needs to be discussed in some detail. The general results are given in Table (7). This time, the number of tokens in each box of Table (7) should be equal to the number of words multiplied by three repetitions and 40 speakers. However, as for the first wordlist, unknown words were excluded, which results in the total number of words being lower than the theoretical maximum.

To the exception of <-p>, all codas have one very predominant realization that suffers few exceptions. As we have seen before, <-p> has two possible modern reflexes, [-p] and [-wʔ], depending largely on the frequency and status of the word. The experiment further suggests that the choice of one variant over the other is not predictable from voice quality. Only seven words written with final <p> are reported in (7), but my observations of unrecorded speech support this result. There is of course a possibility that some vowels have a probabilistic, non-categorical effect on the choice of a reflex (for example, [-p] could be more common after back vowels than front vowels), but this has not been investigated systematically. As was the case in Table (6), the behavior of other codes is more categorical. Coda <-t> is always realized as [-t] except in the word <haḳĕt> 'what', which can be realized as [kĕʔ~ ḳeʔ ~ ḳe], but is a high frequency function word that could be argued to have an underlying coda glottal stop in the modern colloquial language. Final <-c> is very consistently realized as [-jʔ], except for seven cases of [-j], mostly in the word

<ʃɨc> [ʃɨjʔ] 'seaweed'[8]. Finally, although the Cham script does not distinguish /-k/ and /-ʔ/, they are clearly distinct in the modern language, despite the fact that /-k/ is very rare in non-learned words. The only word ending in /-k/ used in this experiment was <tĭk> 'teapot'. It was always realized with a coda [-k]. Words ending in <-ʔ> in written Cham are also consistently realized with a full glottal stop in modern Cham. Only one word out of 1539 has lost its final <-ʔ>, which clearly shows that coda glottal stops are not deleted. The surprising occurrence of six instances of [-h] is due to the word /çeʔ/ 'to knead', which seems to have two variants, a common one with a coda /-ʔ/ and a less frequent one with a coda /-h/[9].

(7) Realization of Written Cham codas after other vowels (40 speakers)

Written Coda	**<p>** (7 words)	**<t>** (10 words)	**<c>** (5 words)	**<k>** (1 word)	**<ʔ>** (14 words)
Modern realization	546/762[wʔ] 210/762 [p] 3/762 [wp]	972/1080[t] 78/1080 [ʔ] 24/1080[∅] 6/1080 [k]	522546[jʔ] 21/546 [j] 3/546 [∅]	120/120[k]	1512/1539[ʔ] 18/1539 [h] 3/1539 [∅] 3/1539 [p] 3/1539 [k]
% Full stop	***27.6%***	***90%***	*0%*	***100%***	***98.2%***
% Debuccalized	***72%*** [wʔ]	*7.2%* [ʔ]	***95.6%*** [jʔ]		
% Dropped	*0%*	*2.2%*	*0.5%*	*0%*	*0.2%*
% Other	*0.4%*	*0.5%*	*3.8%*	*0%*	*1.6%*

Keeping all these exceptions in mind, we can now summarize the facts presented in (6) and (7) in the following way: Written Cham words ending in <p> are realized in the modern language with either /-p/ or /-wʔ/, with only a minimal amount of variation in the realization of individual words which probably reflects linguistic insecurity rather than actual variation in normal speech. Other codas behave even more consistently: If we exclude the word <hak̥ĕt>, already discussed above, coda <t> is almost always realized as a full stop. The final palatal stop <-c> is systematically realized as [-jʔ], and the only word with a final /-k/ that was looked at did not vary either. Finally, laryngeal /ʔ/ is realized as a full glottal stop and shows few signs of being dropped.

2.1.3 Discussion

The results show that the claim that "… the stops [-p, -t, -k] have fallen together as glottal stop and *h* has been lost altogether" (Phú et al., 1992) is not an accurate characterization of the realization of codas in Phan Rang Cham[10]. In the experiment, the laryngeal /-h/ is never dropped and the oral stops, although frequently debuccalized, are never realized as /-ʔ/ except in one word, <hak̥ĕt> 'what', which can be argued to have a final glottal stop synchronically. Of course, the data discussed here come from a relatively formal situation,

[8] This is not sufficient to claim that there is a tendency to reduce [-jʔ] to [-j]. In the word [ʃɨjʔ], the vowel is strongly glottalized due to glottal constrictions in both the onset and the coda. It is possible that some listeners have reinterpreted this glottalization as stemming exclusively from the onset and have lexicalized the word as [ʃɨj].

[9] Final [-h] is not a regular realization of Common Cham *-ʔ.

[10] My observations in Bình Thuận suggest that the same holds for the Cham dialects spoken there.

wordlist recording, where speakers are likely to speak a language variety unaffected by some phonological processes applying only in colloquial speech. However, short interviews carried out with the same speakers do not show coda deletion or neutralization either and, for what it is worth, my impressions of unrecorded running speech go in the same direction.

Even in the case of <-p>, which can be realized as a full stop or as a glide followed by a glottal constriction, the two variants do not seem to occur in different utterances of the same word, even in different speakers. In (6), some words have one divergent speaker out of 43, but it is likely that these unexpected variations are due to affectedness and to the speaker's awareness that the two codas are written with the same grapheme in the conservative Cham script. In the modern language, the debuccalized coda [-wʔ] is possibly not a free allophonic variant of /-p/ anymore, but should be analyzed as a sequence of /w + ʔ/.

The data presented in this section clearly argue against a simplistic description of Eastern Cham in which codas are dropped and the register allophones preceding them become contrastive. However, it does not address two more interesting issues, namely the realization of the coda-conditioned register allophones and the phonological status of codas, more specifically that of the glottal stop, which could have become a part of the tones, while still being realized on the surface. These questions are addressed in Sections 2.2 and 2.3, respectively.

2.2. Coda-conditioned register allophony

Now that I have established that codas have not been deleted and are still realized on the surface, what is their exact effect on the pitch height and contour of the registers? An acoustic experiment was carried out to determine the nature of this effect.

2.2.1 Methods

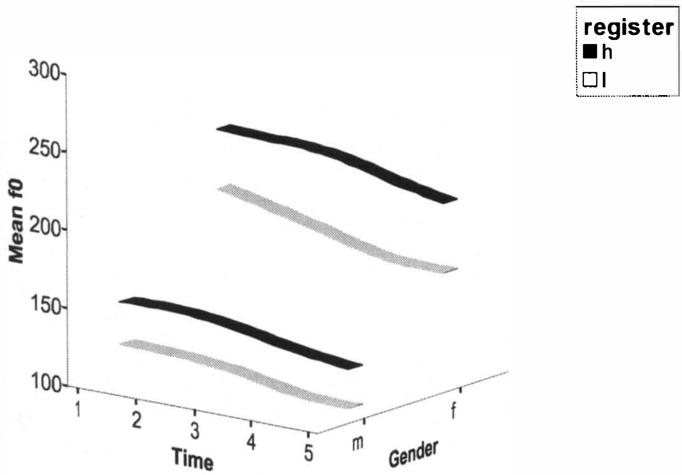
All words containing the vowels /a:/ and /ă/ recorded from 43 speakers for the previous experiment were used to determine the realization of pitch before the various codas. Pitch (f0) was measured with Praat 4.2 at the beginning and endpoint of the vowels and at three equidistant intermediate points.

2.2.2 Results

As we have seen in the introduction, the exact realization of the register allophones is the subject of conflicting descriptions. In order to quantify the data across speakers, the pitch allophones of male and female speakers have been averaged out. As most previous discussion revolves around open syllables and syllables closed by glottal stops, I have plotted the allophones of three pairs of words in Charts (8-10):

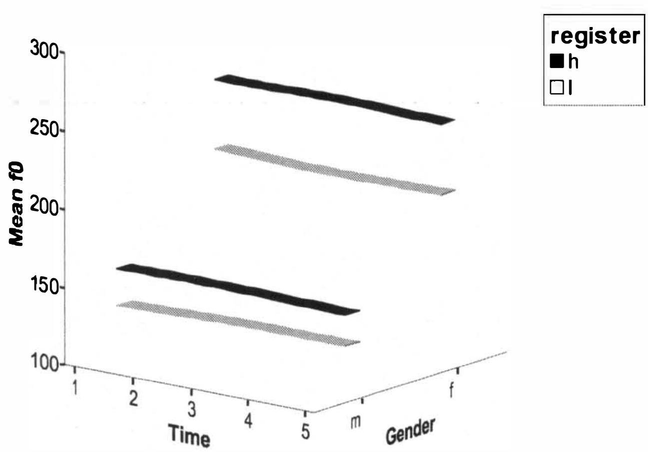
- Open syllable words: /pa/ 'to cross' ~ /p̥a/ 'to carry' (8)
- Syllables with a short vowel closed by a glottal stop /păʔ̣/ 'at' ~ /p̥ăʔ/ 'full' (9)
- Syllables with a long vowel closed by a glottal stop /paʔ/ 'four' ~ /p̥aʔ/ 'to take a walk' (10).

In these charts, the mean duration of long vowels is 155 ms. compared to 79 ms. for short vowels.



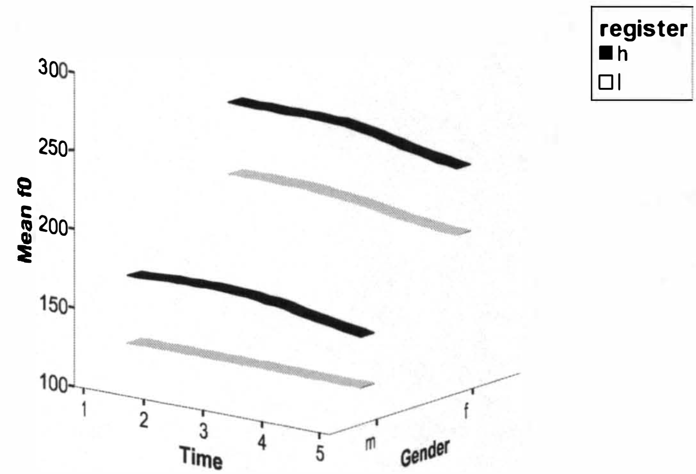
(8) f0 curves of /pa/ and /p̤a/, (20 women, 23 men)

In open syllables (8), the f0 of the two registers is slightly falling for both men and women, the overall pitch range of women being much higher than the pitch range of men. As expected, the pitch of the high register is higher than the pitch of the low register. By contrast, in syllables with a short vowel closed by a glottal stop (9), f0 at the onset of curves is higher by 10-20 Hz and is level instead of falling.



(9) f0 curves of /păʔ/ and /p̤ăʔ/, (20 women, 23 men)

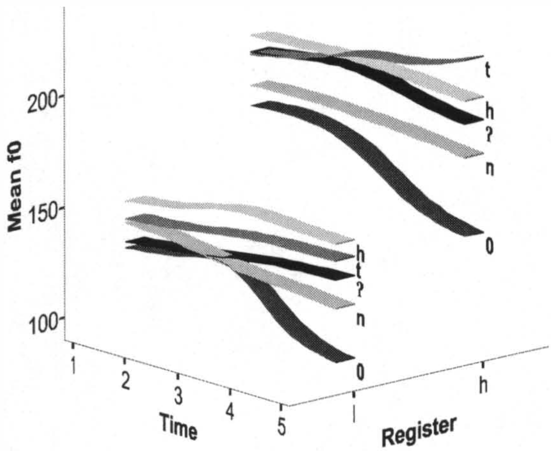
Syllables with a long vowel closed by a glottal stop (10) fall in between: While their overall f0, especially at the beginning of the curve, is about 10-20 Hz higher than in open syllables, their pitch contours are not level like the pitch contours of their short vowel counterparts, but rather slightly falling like the pitch of open syllables. The non-falling pitch of the short vowels could be a consequence of their duration: pitch has a tendency to fall, but the drop does not have time to occur in short vowels.



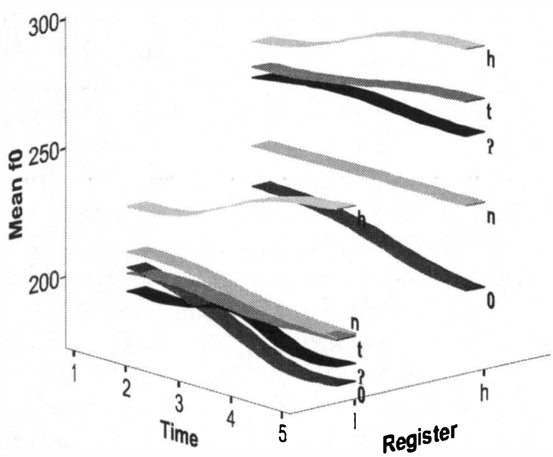
(10) f0 curves of /paʔ/ and /p̤aʔ/ (low register: only three speakers)

Chart (10) requires a caveat: only three educated speakers were aware of the existence of the word /p̤aʔ/, 'to take a walk', and they all insisted that this word is not used in normal speech. It seems to be an artificial colloquial rendition of the written Cham word <kalip̤aʔ>. Therefore, results for the low register on a long vowel closed by a glottal stop may or may not be meaningful, although they go in the same direction as their high register counterpart.

Having compared the pitch of open syllables and syllables closed by glottal stops, we can now look at the effect of other codas on the pitch of the two registers. I give representative data from one male speaker and one female speaker in (11) and (12). To avoid overcrowding the charts, I have chosen to illustrate the f0 curves of vowels belonging to both registers before a limited set of representative codas. Besides open syllables, the two laryngeal codas /-h/ and /-ʔ/ have been included, along with one coda sonorant /-n/ and one coda stop /-t/. We see in both figures that the mean f0 of open syllables has a falling curve that contrasts with the relatively flatter f0 of other allophones. Moreover, open syllables tend to have the lowest overall pitch height. Vowels closed by an /-n/ are a little higher in pitch and also have a slightly falling contour. The other consistent fact is that vowels closed by an /-h/ have a relatively high pitch contour, which is rising for the female speaker (12), but level for the male speaker (11). The remaining two codas, /-ʔ/ and /-t/, are less predictable: their relative pitch is high and flat in the man's speech, but there are inconsistencies between registers in the women's speech. The exact realization of pitch in front of various codas also tends to vary across speakers, a variation in all likelihood due to differences in the exact degree of laryngeal constriction during production of the glottal stop (and possibly /-t/).



(11) f0 curves of the coda-conditioned allophones of the two registers, male speaker born in 1933



(12) f0 curves of the coda-conditioned allophones of the two registers, female speaker born in 1950

2.2.2. Discussion

We have seen in Section I that authors disagree on the exact nature of coda-conditioned register allophony. Their descriptions are summarized in (13). The only syllable types for which all authors agree are the open syllable and the syllable closed by a sonorant. While

Moussay has a symmetrical four-allotone system (2 allophonic contexts X 2 registers), Blood and Phú *et al.* have two allotones in one register and one in the other, the difference being that the register exhibiting allophony is the high register for Blood, but the Low register for Phú *et al.*

(13) Effect of codas on the pitch of the two registers

Register	Coda	Blood (1967)	Moussay (1971) Hoàng (1987)	Phú *et al.* (1992)
High	Sonorants	High	Level	Not tested
	Open syllable			High
	Glottal stop	Higher	Rising	
	-h		Level	Not tested
	Oral stops			
Low	Sonorants	Low	Low	Not tested
	Open syllable			Low
	Glottal stop		Falling	Rising
	-h		Low	Not tested
	Oral stops			

If we exclude the impressionistic descriptions and focus on experimental work, a comparison of the results presented in (11) and (12) with Phú *et al.* (1992)'s findings highlights a few similarities and many differences. As the two studies look at the f0 contours of the *same* Cham words, these differences are puzzling. In both datasets, the pitch height of the register allophones is higher in front of a glottal stop than in open syllables. However, the pitch contours of the various register allophones are very different. The contour of open syllable words in Phú *et al.* is level, while it is falling in our experiment. The same is true of words with a high register long vowel closed by a glottal stop. The way in which these words were uttered could explain these basic differences: Phú *et al.* have recorded the words in isolation whereas they were recorded in a wordlist in the present experiment. Unfortunately, this does not account for the very significant discrepancies in the pitch contour of low register words closed by glottal stops. According to Phú *et al.* (1992), this contour is rising on long vowels and rising-falling on short vowels, a result that contrasts with the level and slightly falling contours found in our present experiment.

One possible explanation for these conflicting descriptions could be variation between speakers and between dialects. However, despite some definite differences between the pitch contours and heights of the different speakers recorded for this experiment, the overall similarities are strong enough to suggest that the mismatch between the different descriptions given in (13) is due to their impressionistic nature rather than to actual production differences. More data on more varieties of the language is obviously needed, but perhaps we also need to abstract away from simple description and to consider the significance of allophony and its variation.

Knowing that codas are maintained in Eastern Cham, would we necessarily expect allophony to be consistent across speakers? Obviously, there should be broad similarities between speakers, but as long as contrast is encoded in the coda rather than the pitch contour or height of the allophones, variation will not lead to confusion and will not hinder communication. Therefore, some variation could easily be maintained. For example, if the transition from modal phonation to glottal constriction is very abrupt and crisp at the end of a vowel, the pitch of that vowel could be kept constant (or even rise slightly because of a tensing of the vocal folds) until the beginning of the glottal stop. By contrast, if a speaker produces glottalization by gradually constricting their glottis at the end of the vowel, then glottal adduction will impede their vocal fold vibration and cause a gradual drop in pitch. If pitch allophony had become contrastive, i.e. if Eastern Cham had tones, this type of variation in the speech signal would not be expected, because it would hinder tone discrimination by listeners.

Taking this in consideration, it becomes meaningless to try to subdivide each register in two or three allotones, as has been proposed by most other authors so far. Obviously, each coda has its own effect on the pitch of the vowel preceding it. Charts (11) and (12) show that the allotones cannot be arbitrarily forced into a small set of discrete categories, as we would expect if there was phonological allotony, but that they rather spread across the whole pitch range, without any cut-off boundaries, a good indicator that the process in strictly phonetic.

Ultimately, the description of coda-conditioned register allophony is an empirical question that would be relevant to the question of tonogenesis only if it could be demonstrated that the register allophones have been phonemicized or that all or some codas are optionally dropped or reanalyzed as suprasegmentals. The frequent variation in the realization of the pitch contour and height of the allotones argues against phonemicization. Further, it has been shown in Section 2.1 that codas are not deleted. Therefore, the only remaining argument in favor of phonemicization of register allotones, i.e. tonogenesis, would be that glottal stops or other consonants are realized on the surface but have been phonologically reanalyzed as suprasegmentals. This argument is evaluated in the next section.

2.3. Evidence against a suprasegmental glottal stop

Since Eastern Cham codas are preserved, the coda-conditioned variants of the two registers are predictable, and we cannot treat them as phonemic tones. However, could some of the Eastern Cham codas be realized on the surface, but be phonologically analyzed as suprasegmentals? More specifically, can a glottal stop be "a part of the internal stuff of a given tone" (Phú et al., 1992), while still being realized on the surface just as if it was a coda?

It is well-known that many Southeast Asian tones have glottalized tones, i.e. tones that are accompanied by a glottal constriction (or creakiness). Standard Vietnamese, to choose a language in close contact with Eastern Cham, has two glottalized tones, called *nặng* and *ngã*, that are respectively a falling tone closed by a glottalization and a falling-rising tone broken by glottalization (Brunelle, 2003, Han, 1969, Hoàng, 1986, Michaud, 2005, Nguyễn and Edmondson, 1997, Phạm, 2001, Vũ, 1982). On the surface, open syllables with the tone *nặng* sound just like words with a low falling tone and a coda glottal stop. However, the phonology of Vietnamese provides ample evidence that this glottalization is a part of the tone. Although Vietnamese can only have simplex codas, *nặng* is found on words ending in sonorants and a few types of phonological processes like reduplication and a word game involve alternations between *nặng* and other tones. No such processes are found Eastern Cham. To my knowledge, there is not a single piece of evidence that coda glottal stops have become suprasegmental in that language: glottal stops are always phased with the end of the rime, they can never be combined with other codas and they are never separated from their codas.

3. Onsets and Registers

We have seen in the previous section that there is no evidence that Eastern Cham already has a full-fledged tone system stemming from the loss of consonantal contrast in codas. I argue elsewhere that there are reasons to believe that Eastern Cham is not even evolving in that direction (Brunelle, 2005a). However, the two registers of Eastern Cham could still have become a simple two-tone system (Blood, 1967, Thurgood, 1999). This possibility in explored in the next few pages. In Section 3.1, I describe the similarities between the registers of Eastern Cham and more typical forms of tones. In Section 3.2, I then proceed to an acoustic analysis of register, followed by a perceptual study in Section 3.3. Based on the results on the results of these two sections, I conclude that, although a two-tone analysis cannot be excluded based on phonetic data only, the registers of Eastern Cham are better treated as a relatively conservative form of register.

3.1. The tonal appearance of Eastern Cham registers

Superficially, Eastern Cham is similar to tone languages in three respects. First, a combination of two diachronic processes, register-spreading and monosyllabicization, has led to the emergence of a number of sonorant-initial minimal pairs distinguished only by their register:

(14)	*Written Cham (reading)*	*Colloquial Eastern Cham*	*Gloss*
	<ini> [ini]	/ni/	'this, here'
	<p̥ani> [p̥an̥i]	/n̥i/	'nativized Islam'
	<ala> [ala]	/la/	'snake'
	<p̥ila> [p̥il̥a]	/l̥a/	'ivory'
	<talah> [talah]	/lah/	'lost'
	<t̥alah> [t̥al̥ah]	/l̥ah/	'tongue'

In many register languages, register is neutralized in sonorant-initial syllables. The register contrast is typically restricted to stop-initial syllables, where it originates. In contrast, co-occurrence restrictions between tone and onsets are rare. The fact that the register contrast of Eastern Cham is found in all types of onsets except implosive stops and preglottalized glides is thus reminiscent of tone.

Second, the phonetic correlates of register are realized on the vowel rather than the onset, with the exception of pitch and amplitude which can be realized on onset sonorants. Further, as emphasized in most descriptions, pitch plays a major contrastive role in the register system of Eastern Cham. As these three characteristics are also found in tone, we could claim that Eastern Cham registers have evolved into a two tones.

However, there is also evidence that Cham is not a tone language. It comes from a word-game called *ɗom k̥ac* 'inverted speech' (Brunelle, 2005b). This word game involves permutations of the onset and rime of a phrase to create a comical effect. For example,

/**naw puh**/ 'to go to the dry rice field' becomes /**nuh paw**/ 'to set a trap'. The crucial fact here is that when two monosyllables have different registers, register follows the consonant rather than the rhyme:

(15)	**k̥aj klɔŋ**	**k̥ɔ̆ŋ klaj**
	club	rutting - penis
	club	*erect penis*

(16)	**p̥u klɔh**	**p̥ɔh klu**
	congee - cut, separate	fruit - testicle
	congee with small noodles	*testicle*

The fact that register always moves with the onset is good evidence that register is still a phonological property of onsets, even if it is realized on the rime. An alternative analysis is that register has become a form of lexical tone and that the rules of the word game always force this tone to follow the onset. Since the type of word game presented here is found throughout Southeast Asia (i.e. in Vietnamese) and usually allows the independent movement of the tones, I favor the first analysis. However, as this paper focuses on phonetic evidence, I leave this question open.

3.2. Acoustic experiment

In order to determine the relative importance of factors such as pitch, voice quality, vowel quality and vowel length in the production of Eastern Cham registers, an acoustic experiment was carried out. My results support Phú et al. (1992)'s findings: pitch and voice quality are the main acoustic correlates of register. However, the registers of many speakers also have distinct F1 (vowel height) and intensity (amplitude).

3.2.1. Methods

The acoustic experiment is based on the wordlist containing the vowels /a:/ and /ă/ that is described in Section 2.1.1. These vowels were selected, because they are more reliable for acoustic measurement of voice quality (spectral tilt). A low first formant can boost the amplitude of the lower harmonics on which spectral tilt measurements crucially depend. Since the vowel quality /a/ has a high first formant, it is better suited for these measurements.

The duration of the onsets, vowels, codas and rimes of all the target words were measured and corrected for speech rate. Because the overall duration of onset stops is difficult to measure (it is impossible to distinguish the closure from a possible pause between them and the previous word), only their voice onset time was measured. In order to filter out the effect of speech rate on duration measurements, a ratio was calculated by dividing the target segment by the duration of the syllable /khăn/ 'word' in the frame sentence. Whenever speakers produced /akhăn/ 'word' as the hypercorrect /khărn/ and /khăr/ or as /panoc/, which originally means 'speech' but is used for 'word' by some speakers, duration measurements were excluded from the results.

All other measurements were made at the beginning, 2/5, midpoint, 4/5 and endpoint of the onsets, vowels, codas and rimes of target words. The following acoustic measurements were made:

- Sonorant onsets:
    - Pitch (f0)
    - Amplitude (intensity)
- Vowels and rimes:
    - Pitch (f0)
    - Amplitude (intensity)
    - Vowel quality (F1 – vowel height - and F2 – vowel frontness/backness)
    - Voice quality (Spectral slope – high coefficients indicate breathiness)
        - H1-H2 (Amplitude of first harmonic – amplitude of second harmonic)
        - H1-A1 (Amplitude of first harmonic – amplitude of peak harmonic of first formant)
        - H1-A3 (Amplitude of first harmonic – amplitude of peak harmonic of third formant)

All f0 measurements had to be visually inspected for doubling and halving. Clear cases were corrected, but ambiguous values were excluded. Since the voice quality measurements were also dependant on pitch measurement (F0 values were used to determine the frequency of the first harmonic in the scripts), all voice quality measurements related to problematic f0 data were excluded.

In order to filter out the effect of codas, onsets and word shape on register, a statistical analysis was run on the acoustic data. For the purpose of the statistical analysis, all target words were divided into the following eight word types:

(17)	pa:C	pa:S	p^{h}a:C
	paC	paS	p^{h}aC
	Sa:C	Sa:S	

C = stops, laryngeals or #
S = sonorants (except laryngeals)

The reason for breaking down the wordlist into categories is to avoid having an unnecessarily large array of variables to interpret and to avoid comparing word shapes with qualitative rather than quantitative differences. It is also important to note that some word types that are found in the wordlist are excluded because they have too few tokens to have any statistical significance (words with a pha:S shape, for example). When words were realized as disyllables, they were grouped according to their final, stressed syllable. A few trisyllabic realizations of the target words were excluded.

The statistical analysis chosen for this experiment is the General Linear Model (GLM). GLMs determine the effect of a set of categorical or gradient factors on a set of dependant variables. GLMs were run for each speaker and each of the 8 word types in order to determine if register is an appropriate predictor for the variation found in the acoustic measurements. All acoustic measurements listed above were used as dependant variables. The factors that were chosen as potential explanations for the variation are the following:

- Type of onset (consonant used as the onset)
- Type of coda (coda used as the onset)
- Type of syllabic template (monosyllabic with simple onset, monosyllabic with cluster onset, disyllabic)
- Register (Low or High)

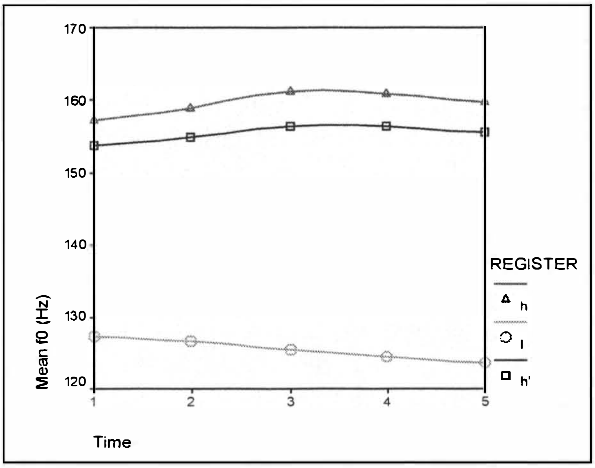
3.2.2. Results

Overall, the acoustic experiment confirms Phú et al. (1992)'s findings. Pitch and voice quality are the most important correlates of the register contrast. Further, the statistical analysis shows that the maximum contrast between registers is timed with the beginning of the rime, not the entire rime, which could either be because register is a phonologically feature of onset consonants or because a suprasegmental register is aligned with onsets.

A more detailed overview of the realization of registers is presented below. Since inter-speaker averages can be misleading, data from a representative man and a representative woman are plotted in charts to give the reader a general idea of the pitch, intensity, formants, voice quality and duration of the two registers. These charts are based on averages of the realization of register on both long and short /a/, in sesquisyllabic and monosyllabic words, and with a wide range of onsets (all possible labial onsets) and codas (stops, laryngeals and open syllables). Therefore, they are only meant to illustrate general tendencies. The statistical significance of the results and a brief overview of the phasing of register with the syllable are given in the text and at the end of the section.

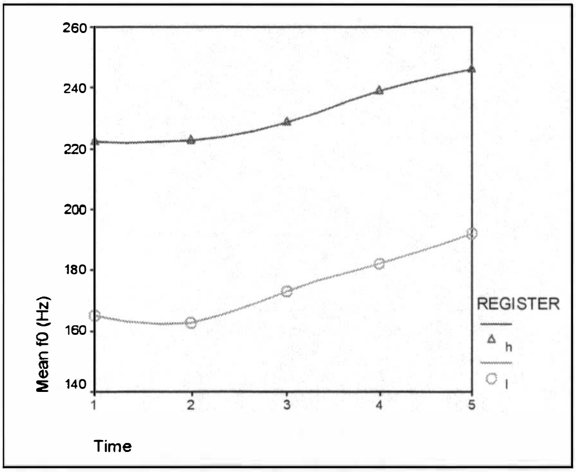
Pitch

Figure (18) shows the average vowel pitch of each register, for a male speaker born in 1977. This speaker is representative of other speakers. F0 is given at five different time points: the onset and the endpoint of the vowel, and three equidistant intermediate points. We see that the pitch of high register words (h) is much higher than the pitch of low register words (l) and that the few words starting with the implosive stop /ɓ/ and the preglottalized glide /ʔw/ pattern with the high register and are therefore labeled (h').



(18) Average f0 during the vowels of a male speaker born in 1977

The same general pattern is found in sonorant onsets, although for historical reasons, words with onset sonorants are never in the neutral register. The behavior of pitch in onset sonorants is illustrated in (19). In this chart, the large f0 difference between registers increases towards the end of the sonorant.



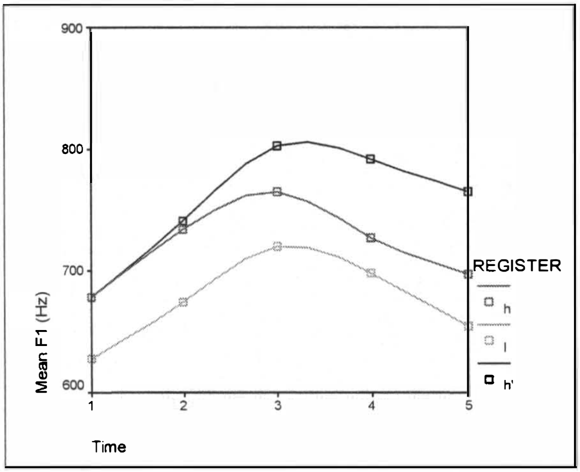
(19) Average f0 during the onset sonorants of a female speaker born in 1950

Amplitude

Amplitude differences vary considerably between speakers: the statistical analysis also shows that amplitude differences between registers are not significant for a majority of speakers. Even for the few speakers that have significant differences, the register that has the highest amplitude is sometimes the low register, sometimes the high one. Because of their limited significance, amplitude results are not plotted here. A more detailed discussion of amplitude results is found in Brunelle (2005a)

Vowel quality

If we now turn to the more interesting question of vowel quality, we find that the differences in vowel height and backness observed between the registers of many Mon-Khmer languages (Huffman, 1976, Miller, 1967, Watkins, 2002) are also present in Eastern Cham, but to a much lesser extent. Overall, as seen in (20), F1 is lower in the low than in the high register. This is expected because of the lengthening of the vocal tract due to the lowering of the larynx during the production of the low register, an articulatory mechanism that will be discussed in Section 3.2.2. The consequence of this lower first formant is that low register vowels should be perceived as more closed than high register vowels. However, the difference between registers is small and we will see in Section 3.3 that it is not used as a perceptual cue.

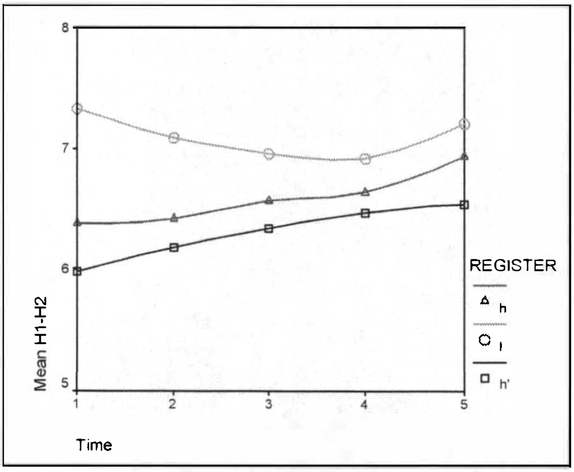


(22) Average F1 of the vowels of a male speaker born in 1977

F2 results are much less coherent than their F1 counterpart. It seems that larynx lowering and vocal tract lengthening do not affect the second formant as much as the first one. Since few speakers have significantly different F2 averages for the high and the low register, these results are not discussed here. A more detailed discussion is found in Brunelle (2005a).

Voice quality

Differences in voice quality are consistent with the results found in many Mon-Khmer languages. When we look at various measures of spectral tilt, the low register is breathier than the high register. The first voice quality measurement, H1-H2, behaves as expected. The low register has consistently higher H1-H2 values than the high and neutral registers, which is an indicator of breathiness. In (21), both subjects have a large difference between their two registers at the beginning of the vowel, but this difference is much narrower towards the end of the vowel, as all tokens become progressively breathier. The fact that the high register following /ɓ, ʔw/ is less breathy than the high register might be due to the glottalization that accompanies the onsets. Since the glottal folds are adducted during the production of these onsets, the vowels following them are produced with a more constricted glottis, which is the opposite of the abduction gesture that accompanies breathiness.

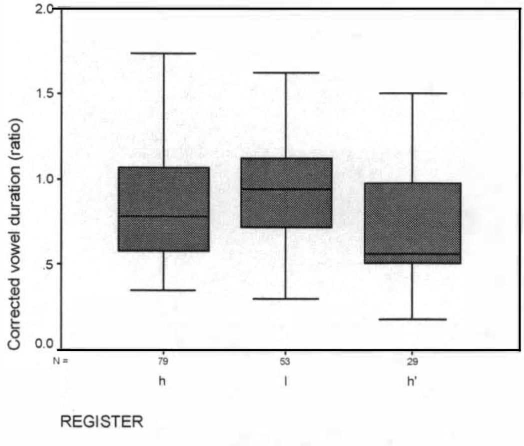


(21) Average H1-H2 on the vowel of a male speaker born in 1977

The same overall tendencies are found for the other acoustic measurements of spectral tilt, H1-A1 and H1-A3 (voice quality), which supports the view that the overall spectral slope, rather than the slope of a specific frequency range, is steeper in breathy vowels than in modal vowels. In fact, the acoustic measurement that seems to capture the voice quality contrast the most consistently is H1-A3, which measures the amplitude difference between the first harmonic and the peak harmonic of the third formant.

Duration

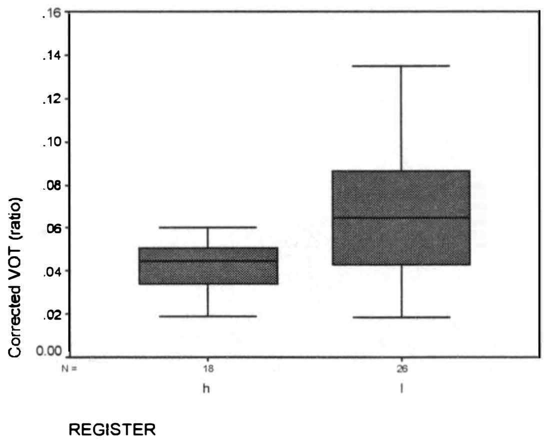
The last type of possible phonetic correlates of register is durational cues. I only present results from words with long /a/'s in this section, but results for words with short /a/'s are similar. There seems to be a tendency for neutral register vowels to be slightly shorter, as can be see in (22). The vowels of the high and low registers are not clearly different.



(22) Vowel duration ratio of the registers of a female speaker born in 1950

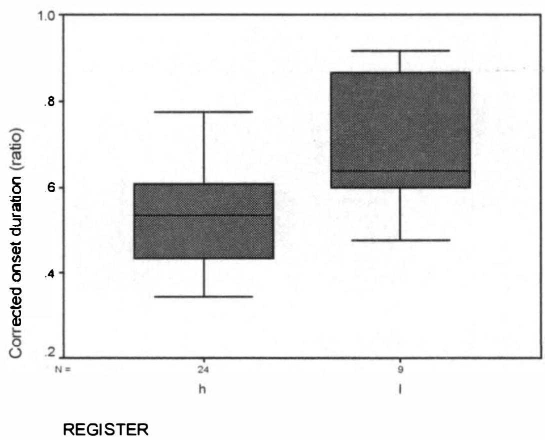
Onsets pattern more differently than vowels depending on the register to which they belong. This is especially true of onset stops, which, in Mon-Khmer languages and in

Javanese, are often slightly aspirated in the low register, but not in the high register (Adisasmito-Smith, 2004, Fagan, 1988, Ferlus, 1979, Hayward, 1993, Maddieson and Ladefoged, 1985). In (23), we see that the VOT of onset /p/ is longer in the low register.



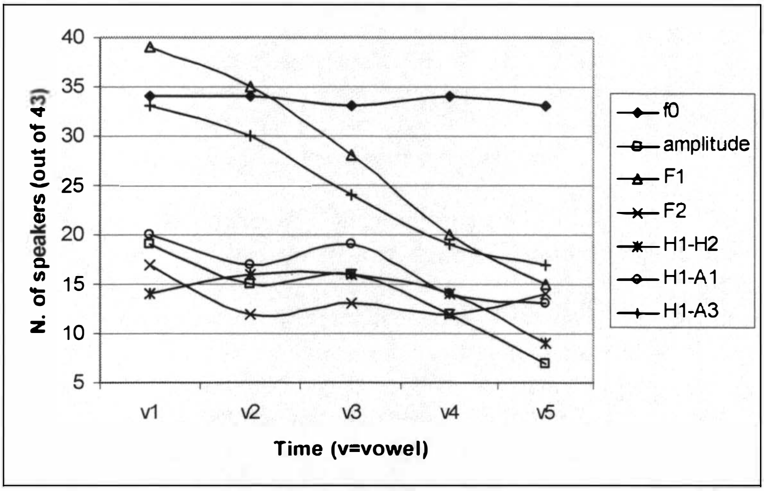
(23) VOT duration ratio of the registers of a male speaker born in 1977 after onset /p/

The durational differences in onset stops also hold for onset sonorants. For example, in (24), low register onset sonorants are longer than their high counterparts. It is therefore tempting to draw parallels with other languages and to claim that onset duration is a crucial feature of Eastern Cham register. Unfortunately, the statistical analysis shows that the durational differences are significant only for a minority of speakers. Therefore, although duration does play a certain role in the production of some speakers, it is not a robust correlate of register.



(24) Onset sonorant duration ratio of the registers of a female speaker born in 1950

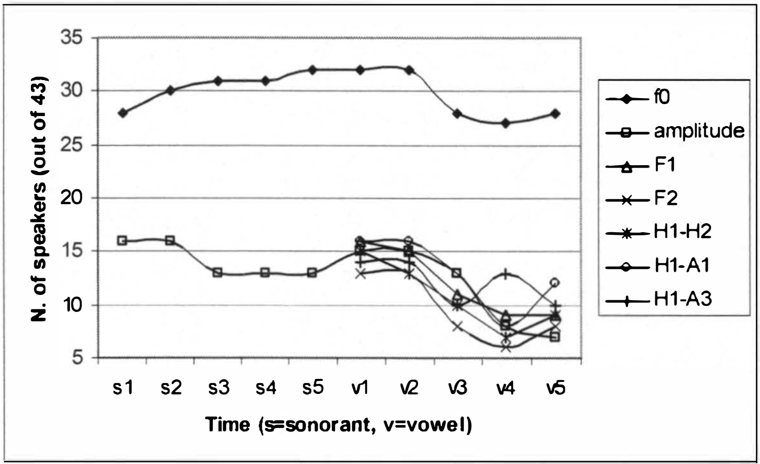
As mentioned during the presentation of these general tendencies, there is a fair amount of between-speaker variation in the acoustic realization of register. This variation is beyond the scope of this paper[11], but it is nonetheless important to emphasize that even if most phonetic correlates of register that were measured in the experiment are used in register production by at least some speakers, three correlates (pitch, voice quality and vowel height) are highly significant in the speech of almost all speakers. To illustrate that point, the results of the statistical analyses run on two representative word types have been plotted as figures. The phasing of register contrast in pV:C words is given in (25) while the phasing of register in SV:C words is given in (26).



(25) Number of speakers who have a significant difference between the High and Low registers for each phonetic correlate in pV:C words

These charts show us the number of speakers who have significantly different mean values for various phonetic correlates in the low and the high register. In the words starting with an onset stop, the pitch (f0), vowel height (F1) and voice quality (H1-H3) of high and low register tokens are distinct for the great majority of speakers at the beginning of the vowel. The F1 and H1-H3 values of two registers are much less distinct at the middle of the vowel and are generally not distinguishable at vowel endpoint. Pitch on the other hand remains clearly distinct throughout the vowel for most, but not all speakers.

[11] A full description of inter-speaker variation, both structural and sociolinguistic, can be found in Brunelle (2005a).



(26) Number of speakers who have a significant difference between the High and Low registers for each phonetic correlate in SV:C words

A similar pattern is found in monosyllables starting in a sonorant (26), but to a different degree. Onset sonorants are interesting because pitch (f0) and intensity (amplitude), which cannot surface on onset stops, can be realized on them. Once again, F0 (pitch) is very distinct at the end of the onset sonorant and the beginning of the vowel. All other phonetic correlates are distinct for one quarter to one third of the speakers at the beginning of the vowel, but then become less significant later on in the vowel.

3.2.2. Discussion

Although speakers mostly make use of pitch, there are different individual strategies to realize the register contrast. In addition to pitch, some speakers also realize the contrast through voice quality, intensity or F1, while others do not. This between-speaker variation in the realization of register was also found in Wa (Watkins, 2002). Should we then claim that each speaker has her own production strategy or should we rather assume that there is a general articulatory mechanism for register (and that each speaker grafts his own idiosyncrasies to it)? The second solution would obviously be more economical, but it can be considered only if we can propose a physiological model of register production. Since the study presented in this section is acoustic in nature, it is difficult to propose an articulatory model. However, I believe that by combining our knowledge of the diachronic formation of register and of the acoustic realization of articulatory gestures, such a model can be proposed.

It seems that the primary mechanism underlying register production in the early stages of registrogenesis is the vertical movement of the larynx. Originally the downwards movement of the larynx is a way of facilitating stop voicing by increasing the subglottal air pressure, but as voicing is neutralized, it is preserved along with its various acoustic consequences (Ferlus, 1979). A full exposition of the arguments in favor of laryngeal movement is beyond the scope of this paper. However, the physiological evidence that the downwards movement of the larynx is originally responsible for register production is the following:

1) The pitch difference between registers: because the spine is curved, the larynx rotates slightly when it moves down, which reduces the tenseness of the vocal folds and lowers pitch (Honda et al., 1999).

2) The voice quality difference between registers: the increased transglottal pressure due to laryngeal lowering causes perturbations in vocal fold vibrations that are perceived as breathiness.

3) The vowel quality difference between registers: the length of the supraglottal tract is lengthened by lowering the larynx, which raises formant values. The expansion of the pharynx that possibly contributes to the original voicing contrast by lowering supraglottal pressure can also enhance vowel quality differences by pushing the root of the tongue forward, and as a result, the tongue tip as well.

However, at a later diachronic stage, an acoustic correlate can be emphasized by adding active control to a specific articulator (Ferlus, 1979). In the present case, the pitch difference between registers can be enhanced by tensing or laxing the vocal folds through direct control of intrinsic laryngeal muscles. Similarly, vowel quality differences can be enhanced by directly controlling tongue muscles, in addition to the original register movement. As a result, some of the enhancement cues can gradually gain importance and the register distinction could eventually be reanalyzed and maintained through one or a few of these originally ancillary phonetic cues even after the neutralization of vertical laryngeal movement.

The fact that all the phonetic cues that were measured in the acoustic analysis are significant for at least some speakers or word types suggest that vertical laryngeal movement is still present. If it had been neutralized, we would expect speakers to retain only one or two features and to lose all other features. That said, it is clear that pitch plays a more central role in the register distinction of Eastern Cham than in most Southeast Asian register systems. This is good evidence that the pitch contrast is enhanced by speakers, but it is also possible that some speakers enhance other phonetic cues as well. Although articulatory evidence is lacking, the articulatory realization of register should at least include vertical movement of the larynx and some laxing/tensing of the vocal folds.

The active role of vertical laryngeal movement in register realization suggests that the register system of Eastern Cham is relatively conservative in that it preserves the articulatory mechanism that has given rise to its register system, despite its enhancement through direct vocal fold control. In that respect, Eastern Cham is different from other languages, where only enhanced features have been preserved and were the original movement of the larynx has been lost (Huffman, 1976 for Khmer, Mundhenk and Goschnick, 1977 for Haroi).

3.3. Perceptual experiment

A perceptual experiment was carried out to determine which phonetic attributes are the most important perceptual cues in register discrimination. Not surprisingly, the main perceptual cues of register are pitch and voice quality, which is congruent with the results of the acoustic study.

3.3.1 Methodology

Five minimal pairs were recorded by Phú Văn Hẳn, a male native speaker of Eastern Cham born in 1963. The first pair (la/l̥a) was chosen because its two stimuli begin in a sonorant.

The next two pairs start with /p/, but while the second pair has an open vowel, the third one has a laryngeal coda /h/. This contrast was chosen to test the effect of final /h/ on the perception of breathiness. Finally, the last two pairs both have /t/ onsets and /ʔ/ codas, but their vowels contrast in length. It was expected that durational cues would not be as relevant to register discrimination for these two pairs. Note that these target words were recorded in their monosyllabic colloquial form.

(27) Stimuli:

/la/	'snake'	/l̥a/	'stupid'
/pa/	'to cross'	/p̥a/	'to carry'
/pah/	'to hit with the hand'	/p̥ah/	'to dust'
/tăʔ/	'to behead''	/t̥ăʔ/	'to tidy up'
/taʔ/	'bean'	/t̥aʔ/	'pumpkin'

These minimal pairs were uttered in the following carrier sentence, recorded in its colloquial form:

(28) Frame sentence:

/l̥ăʔ poc khăn _____ jwa krɨ khăn ni/
I read word _____ because like word *dem*
'I read the word _____ because I like it.'

The pitch, voice quality, formant frequencies and durations of the stimuli are given in Appendix 1. Values are given for onsets and offsets although the stimuli were also measured at three other equidistant points.

In order to have a more precise idea of the factors that are playing role in the perception of register, some phonetic cues were modified and some stimuli were resynthesized. Ideally, all the phonetic correlates that have been shown to play a role in the register contrast would have been varied to measure their exact effect on perception. However, the number of resulting stimuli would have been too high to run the perceptual experiment in one session per subject. Further, the original stimuli were modified using Praat 4.2, which limits the types of resynthesis that can be done. My attempts at modifying voice quality, for example, resulted in stimuli that did not sound natural to my listeners. Therefore, only two parameters were modified: pitch and duration. Pitch clearly plays a role in the register contrast. As for duration, it was included because a pilot study led me to believe that it might be relevant to the production and perception of register, a hypothesis that later turned out to be less well-supported than expected, as seen in the previous section. In any case, the stimuli where then modified in three ways:

1) Pitch was *modelized*, i.e., it was smoothed by rounding up the f0 values at vowel onset and offset to the closest multiple of 10 and by interpolating a straight pitch curve between these two points. Words with open vowels were treated differently, because a straight interpolation sounded too artificial to the subjects in a preliminary experiment. They were assigned a third pitch target at their mid value

in order to generate a flat pitch curve on the first half of the vowel followed by a falling curve on the second half.

2) The pitch curve was replaced by the pitch curve of the modelized token of the other member of the pair. For example, the pitch of the *p̥a* was replaced by the modelized pitch of *pa*. These tokens are called *inversed* tokens.

3) Pitch was neutralized by replacing it with an average of the modelized pitch of the two members of the pair. For example, the *neutralized* token of *p̥a* has a pitch value that has been obtained by averaging out the modelized pitch targets of *p̥a* and *pa*. The goal of these pitch manipulations is to determine the role of pitch by measuring the changes in register perception when pitch is modified while keeping other factors constant.

The duration of these three types of tokens was then modified. The onset of high register tokens was lengthened by a factor of 1.5 without changing the duration of the vowel. The duration of the vowel was also lengthened by a factor of 1.5, without modifying the duration of the onset. The opposite was done for low register tokens: both their onsets and vowels were shortened by a factor of 1.5. The aim of these duration manipulations was to weigh the role of duration in register perception and its interaction with pitch, although this effect turned out to be less important than expected, as mentioned above.

Voice quality was kept constant. The initial pairs of stimuli that were chosen for the experiment have markedly different voice qualities at their vowel onsets. The low register member of each pair has a higher H1-H2 value, i.e. a breathier voice at vowel onset. Since the acoustic study showed that the two registers do not always have a robust voice quality contrast at vowel offset, this criterion was not retained in the selection of the natural stimuli. Another factor that was left aside, this time for technical reasons, is the frequency of the first two formants. Attempts at manipulating formants made the stimuli sound artificial to the subjects. By and large, manipulation of one phonetic dimension had little effect on others. Changes in pitch obviously resulted in minor changes in formant frequencies as harmonics frequency was modified. Pitch changes also affected voice quality to some extant, as they modified the frequency of spectral peaks. However, durational manipulation merely stretched or compressed the stimuli without effects on other phonetic dimensions.

In total there were 100 stimuli which were played to the 30 subjects in three separate sub-experiments. The nine female and 21 male subjects were all native speakers of Eastern Cham living in Hồ Chí Minh City. Twenty-four of them were originally from Ninh Thuận province and six from Bình Thuận and all of them were college-educated. This subject sample is less diverse in terms of age and socioeconomic background than the sample used for the production study, but at the same time, it is more diverse in terms of dialectal variation. The choice of subjects was dictated by the fact that I needed subjects who could use a mouse and were not intimidated by computers, and that such subjects were difficult to find in Phan Rang. Further, I was allowed to work freely with Cham speakers on the premises of the University of Social Sciences of Hồ Chí Minh City, whereas every work session in Phan Rang had to be approved by provincial and local authorities, making the enrollment of a relatively large number of subjects for short sessions very difficult.

The experiment was designed as a Praat perceptual setup and was administered to the subjects on a laptop computer. The first sub-experiment included the stimuli based on *la/l̥a*, the second comprised the stimuli based on *pa/p̥a/pah/p̥ah* and the third was made up of the stimuli based on *tăʔ/t̥ăʔ/taʔ/t̥aʔ*. Each stimulus was played three times and the stimuli were played in a random order. Subjects listened to the stimuli through headphones and then selected the word they had heard by clicking a box containing a latin-based transcription and Vietnamese glosses for all possible answers (the two or four possible lexical items used for each sub-experiment). The next token was then played automatically. In the first experiment, there were only two possible answers (*la* and *l̥a*). The second and third sub-experiments had four possible answers each. Subjects did not have the option of not making a choice and were instructed to choose the best possible answer, even if not fully satisfactory. Subjects were allowed to take a short break after every 40 stimuli.

3.3.2 Results

The results of the acoustic analysis suggest that the most salient cues for perception should be pitch and voice quality. F1 could also play a minor role, but duration and amplitude should not have much of an effect on perception. The results of the perceptual analysis largely confirm this. In this section, I present a statistical analysis of the responses of all subjects.

Before starting, a short caveat on terminology is in order: I use the term *correct identification* when subjects identify the register of a stimulus as the register of the natural stimulus from which it was resynthesized. For example, a high-register stimulus that has been resynthesized with a low pitch is *correctly identified* if it is perceived as a high-register token and *misidentified* if it is perceived as a low-register stimulus.

The categorical analysis presented in the previous section cannot account for the effect of small variations in the perception of phonetic cues and determine the relative importance of each phonetic factor in register perception. Therefore, binary logistic regressions were run on the data from each sub-experiment. A regression model takes all the variation in a data set and finds the factor that explains the largest amount of variation in it. It then removes all the variation that can be accounted through this first predictor and finds the factor that accounts for the largest proportion of the remaining variation. This operation, called a stepwise regression, is repeated as many times as required. In the present experiment, the stepwise regression was interrupted when the percentage of cases correctly predicted by the model reached its peak. The factors that were included in the regression model are the normalized duration of the onset and vowel, the f0 and amplitude of the onset, and the f0, amplitude, formants (F1 and F2) and voice quality (H1-H2, H1-A1, H1-A3) of the vowel.

Results for the first minimal pair, /la~l̥a/, are given in (29). Pitch at the midpoint of the vowel (P3), accounts for 60.1% of the variation in the data and, by itself, correctly predicts 84.2% of responses. The next best predictor of the responses given by the subjects is F2 at 4/5 of the vowel. This is unexpected as F2 is not a robust phonetic correlate of register, but note that this factor only explains an additional 2.9% of the variation and 0.4% of the responses, which is at best marginal. Along the same lines, the third significant predictor is F2 at the endpoint of the vowel, which accounts for an extra 0.7% of the variation and 1.2% of responses. Overall, we can conclude that pitch is by far the most important perceptual cue for open syllable with an onset sonorant and that the pitch, intensity and duration of the onset sonorant do not play a role in perception.

(29) la/l̥a

	Cue and time point (P1-P5)	Sig.	Nagelkerke R^2	Percentage of cases correctly predicted by the model
Step 1	f0 P3 vowel	.000	.601	84.2
Step 2	f0 P3 vowel F2 P4 vowel	.000 .000	.630	84.6
Step 3	f0 P3 vowel F2 P4 vowel F2 P5 vowel	.000 .000 .000	.637	85.8

The next pair of words, /pa~p̥a/, also consists of open syllable words, but with onset stops instead of sonorants (30). The same factors have been included in the model, except the pitch and the intensity of the sonorant, which are not relevant in words with onset stop. Moreover, rather than including the normalized duration of the whole onset, only normalized VOT was used. Once again, f0 (pitch) is the most important perceptual cue, but at vowel onset rather than midpoint. It accounts for 54.2% of the variation and 84.8% of responses. At step 2, voice quality at vowel midpoint (as measured by H1-H2) accounts for an additional 5.1% of the variation, but no further responses. Finally, another voice quality measurement, H1-A3 at vowel midpoint, captures another 1.1% of the variation and 0.7% of cases. Once again, f0 alone accounts for a large majority of responses.

(30) pa/p̥a

	Cue and time point (P1-P5)	Sig.	Nagelkerke R^2	Percentage of cases correctly predicted by the model
Step 1	f0 P1 vowel	.000	.542	84.8
Step 2	f0 P1 vowel H1H2 P3 vowel	.000 .000	.593	84.8
Step 3	f0 P1 vowel H1H2 P3 vowel H1A3 P3 vowel	.000 .000 .000	.604	85.5

By contrast, pitch does not play a role in the perception of syllables closed by laryngeals. Results for the minimal pair /pah/p̥ah/ are given in (31). Vowel quality at 2/5 of the vowel, as measured by H1-H2, accounts for 54.5% of the variation and 82.8% of responses. No other perceptual cue correctly predicts an additional proportion of responses.

(31) pah/p̥ah

	Cue and time point (P1-P5)	Sig.	Nagelkerke R^2	Percentage of cases correctly predicted by the model
Step 1	H1H2 P2 vowel	.000	.545	82.8

A similar situation is found for the minimal pair /tăʔ/t̥ăʔ/ shown in (32). Voice quality at vowel midpoint, but this time measured with H1-A3, captures 77.7% of the variation and 93.3% of responses. Again, no other factor accounts for a higher proportion of responses.

(32) tăʔ/t̥ăʔ

	Cue and time point (P1-P5)	Sig.	Nagelkerke R^2	Percentage of cases correctly predicted by the model
Step 1	H1A3 P3 vowel	.000	.777	93.3

Voice quality at vowel midpoint is also the best predictor of responses for the minimal pair /taʔ/t̥aʔ/ (33). This time, however, H1-A1 is the most reliable acoustic cue. It accounts for 57.8% of the variation and 79.7% of responses. Other factors do not increase the proportion of correct predictions.

(33) taʔ/t̥aʔ

	Cue and time point (P1-P5)	Sig.	Nagelkerke R^2	Percentage of cases correctly predicted by the model
Step 1	H1A1 P3 vowel	.000	.578	79.7

In short, while pitch is by far the most important perceptual cue for open syllables, it is not used as a cue when syllables are closed by a laryngeal. Register perception in the syllables closed by a laryngeal depends exclusively on voice quality, although there is variation as to which phonetic correlate of voice quality is chosen.

3.3.3 Discussion

Two acoustic cues are used for perception: voice quality and pitch. Voice quality seems to be the dominant cue in closed syllables (pah, p̥ah, tăʔ, t̥ăʔ, taʔ, t̥aʔ). By contrast, open syllable tokens (la, pa) are distinguished mostly through pitch. Duration does not have a clear effect. Manipulation of the duration of vowels and onsets does not seem to be sufficient to cause misidentification.

Overall speakers rely on the first half of the vowel for perception. All perceptual cues that are used by speakers are timed with the first three measurement points, except F2 in (29), which is timed with the end of the vowel, but accounts for a marginal proportion of correct identification. The timing of relevant perceptual cues with the beginning of the vowel agrees with the results presented in (25) and (26), where we have seen that the acoustic contrast between registers is stronger at the beginning of the vowel.

The fact that different word types are associated with different perceptual cues can be explained by the effect of codas on pitch. We will see in the next section that the laryngeal codas /h/ and /ʔ/ have an effect on the pitch of the preceding vowel. This effect is mostly felt towards the end of the vowel, but it can blur the pitch contrast between the two registers. In short, pitch, the most clearly contrasting phonetic correlate of register, is used as a perceptual cue in open syllables, and possibly in syllables closed by codas that have little effect on pitch (sonorants). However, whenever a coda affects pitch and makes it less reliable for distinguishing register, listeners fall back on the second most salient cue, voice quality.

4. Conclusions

Is Eastern Cham a tone language? Has its register system evolved into a tone system through the interaction of register allophony and coda weakening and deletion? Contrary to what has been claimed by other researchers, the data presented here does not support the hypothesis that codas are dropped or that their pattern of contrast is being modified. There is no evidence that the final glottal stop has become a tonal element either. These conclusions cast serious doubt on the claim that Eastern Cham is undergoing a full-fledged tonogenesis. However, there still exists a possibility that the two registers of Eastern Cham have become two tones, two suprasegmental elements that are distinguished mostly through pitch, but can also have other correlates. In fact, the crucial role of pitch in the register system, along with the monosyllabic character of the colloquial language and the loosening of cooccurrence restrictions between onsets and registers all seem to suggest that Eastern Cham has become a two-tone language. However, there is also synchronic evidence from a word game that register is still a property of onset consonants. This question is addressed in more detail elsewhere (Brunelle, 2005a, Brunelle, 2005b), but the basic facts suggest that Eastern Cham does not have a very developed tone system, if it has tones at all.

Results from the acoustic and perceptual experiments confirm that the register distinction of Eastern Cham is phonetically realized and perceived through pitch and voice quality, the low register having a lower pitch and a breathier phonation than the high register. However, contra Phú et al. (1992), our results suggest that F1 is higher for the low register than the high register. This higher F1 is due to the lower position of the larynx during the production of the low register, a feature that can be traced back to the original voicing contrast that gave rise to register. Another conservative feature of Eastern Cham register is the longer duration of low register onsets in the speech of some speakers, which is reminiscent of incipient register systems elsewhere in Southeast Asia.

The diachronic implications of these findings are beyond the scope of this paper, but models of contact-induced registrogenesis and tonogenesis should be able to integrate these phonetic facts and should be grounded in a sociophonetic investigation of the variation found in the speech community.

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Appendix I

Phonetic correlates of register in the unmodified stimuli used for the perceptual experiment

	f0 onset (Hz)	f0 offset (Hz)	H1-H2 onset	H1-H2 offset	F1 onset (Hz)	F1 offset (Hz)	F2 onset (Hz)	F2 offset (Hz)	Onset /VOT duration (msec)	Vowel duration (msec)
l̥a	158	135	8,8	8,2	553	793	1696	1502	192	295
la	192	162	6,5	8,5	683	679	1568	1603	86	262
p̥a	154	126	7,8	8,5	590	739	1241	1429	20	334
pa	183	156	5,9	9,7	685	742	1217	1456	13	278
p̥ah	171	171	8,4	10,9	562	721	1255	1410	21	104
pah	208	203	5,1	9,7	638	729	1136	1549	13	114
t̥ăʔ	172	183	10,0	6,2	661	792	1686	1492	12	122
tăʔ	213	214	5,2	6,7	711	802	1274	1489	9	102
t̥aʔ	159	168	11	6,3	696	807	1636	1470	13	232
taʔ	206	197	5,3	8,7	711	802	1274	1489	10	198

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