Sound changes following the loss of /r/ in Khmer: a new tonogenetic mechanism?[*]

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Abstract

This study reports an acoustic investigation of recent sound changes in the Phnom Penh dialect of colloquial Khmer (Cambodian). Monosyllabic words of $C_1rV(V)(C)$ structure (where C_1 is an obstruent) produced in colloquial and careful reading pronunciations were acoustically analyzed. The analyses revealed that, in the colloquial pronunciation the /r/ has been lost and the words are now produced with a falling-rising pitch contour. C_1 has been aspirated and both short and long front [a] have been diphthongized to [ea]. A phonetic explanation based on aerodynamic factors is proposed to account for the observed changes.

1. Introduction

Physiological constraints of the articulatory and/or auditory mechanisms have been proposed as the source of sound changes for some time (e.g., Hombert 1977 and references therein, Ohala 1971, 1974, 1981b, 1989, 1993). As pointed out by Hombert (1977), these explanations imply that the speaker's pronunciation may not be perceived as intended. A distortion may occur due to articulatory and auditory processes, which affect the way the sounds are produced and perceived by listeners. Ohala (1993) reviews many sound changes and proposes a typology of sound change in which variation in speech due to coarticulation (among other things) can fail to be corrected by the listener (hypo-correction) or corrections can be erroneously applied (hyper-correction). As coarticulations or reductions are greater in faster speech (e.g., Guion 1998, Moon, Lindblom & Lame 1995; Lindblom 1990), one might expect more hypo-correction in fast speech forms.

Preliminary evidence for such a proposal was given in Guion (1998) in which faster speech forms were found to be more similar acoustically to post sound change forms than citation speech forms. In this study, the English voiceless velar stop /k/ before the high front vowel /i/ was found to be

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acoustically more similar to the palatoalveolar affricate /tʃ/ in faster speech than in citation forms. Results of perception experiments also revealed that /k/ before /i/ was often heard as /tʃ/. These findings suggested that the prevalent sound change from /k/ to /tʃ/ in many of the world's languages might have been due to a perceptual reanalysis of the anticipatory coarticulatory effect from /i/ to /k/ produced in fast speech.

The goal of this paper is to report on sound changes accompanying the loss of the alveolar trill /r/ in colloquial Khmer. This includes aspiration of *onset obstruents, diphthongization of monophthongs and more importantly the* development of a falling-rising pitch contour. Based on previous research, it will be proposed that these developments are largely phonetically motivated. The paper is divided into 7 sections. In Section 2, an overview of Khmer, including its phonological structures (vowels, consonants and word structure) is outlined. Previous reports on tone development and other accompanying sound changes in Khmer are reviewed in Section 3. Section 4 gives an overview of the goals and the scope of this current study. Major tonogenetic mechanisms are reviewed and a proposal for a new tonogenetic mechanism is made in Section 5. Acoustic analyses and descriptions of tone development and other accompanying changes are presented in Section 6. Finally, a discussion of the results and concluding statements are presented in Section 7.

2. Khmer: an overview

Cambodian, or Khmer, the proper ethnolinguistic term, belongs to the Mon-Khmer group of languages of the Austroasiatic family. This language family is comprised of several hundred related minority languages scattered from India to the South China Sea, such as Khasi in India; Mon, Palaung, and Wa in Burma; Khmu, Loven and So in Laos. These Mon-Khmer languages are distantly related to the Munda languages of Northern India, Nicobarese in the Nicobarese Islands, and Vietnamese and Muong in Vietnam (Huffman 1978a). Besides being the national language of Cambodia, Khmer is also the common language of Khmer settlement areas. This includes the MeKhong Delta region of the southern part of Vietnam and at least 12 provinces in the lower part of the northeast and east of Thailand bordering Cambodia (Premsrirat 1995). The Khmer spoken in the lower part of northeast Thailand is referred to by Smalley as Northern Khmer (Smalley 1964, 1976). However, the Khmer dialect spoken in Phnom Penh, Cambodia, is considered the standard one. Like most other Mon-Khmer languages, Khmer differs from other languages spoken in the same geographical region including Thai, Lao and Vietnamese. It is a non-tonal language. However, some tonal Mon-Khmer languages exist. According to Svantesson (1989), this includes Danaw, Riang, Wa, Man Met, Mang, Lai and notably Vietnamese.

The existence of an earlier phonation type (i.e., breathy vs. clear or modal voice) contrast due to the historical process of devoicing of consonants turning initial voiced stops /b, d, j, g/ into voiceless ones /p, t, c, k/ has been proposed for Khmer. This process resulted in the older consonantal distinction being transferred to the following vowels, causing the vowel system to split into two sub-systems. These two vowel systems have variously been termed 'a series' and 'ò series' vowels (e.g., Maspéro 1915), 'first register' and 'second register' (Huffman 1978b), or 'high' and 'low' register vowels (Martin 1975). The 'first' register is associated with a 'normal' or 'head' voice quality, and the 'second' register is associated with 'breathy' or 'sepulchral' voice quality (Henderson 1952). Henderson also noted that vowels of the 'first' register are generally more open in quality than those of 'second' register. 'First' register vowels are also produced with a relatively higher pitch than 'second' register vowels. It is the pitch level associated with different voice qualities that is believed to have given rise to tonal distinction in Vietnamese.

This earlier voice quality distinction, however, no longer exists in any modern dialects of Khmer spoken in Cambodia (but see Wayland 2003 for a description of a dialect of Khmer spoken in Thailand that appears to have kept this historical contrast). In all modern dialects of Khmer spoken in Cambodia, the difference between the earlier 'first register' or 'modal' and 'second register' or 'breathy' vowels can now be distinguished on the basis of vowel height and/or diphthongization (Huffman 1978b). To our knowledge, no voice quality accompanying vowel quality distinction has ever been reported for any of the Khmer dialects spoken in Cambodia.

Khmer phonological systems

2.1 Khmer consonants

The Khmer consonant system (Table 1) as described in Henderson (1952), Huffman (1967), Jenner (1969) and Nacaskul (1978) is rather stable from dialect to dialect.

Table 1. Khmer consonants.

	Bilabial		Dental/alveolar		Palatal	Velar	Glottal
Plosives	p	b	t	d	c	k	ʔ
Fricatives	f		s				h
Nasals	m		n		ɲ	ŋ	
Liquids			l	r			
Glides	w				j		

/p/, /t/, /k/ are unaspirated when they occur as the first member of a consonant cluster. Both aspirated and unaspirated stops can occur word or syllable initially as in [pəj] ‘flute’, [p^{h}ɨj] ‘to fear’, [taː] ‘grandfather’, [t^{h}aː] ‘to say’, [kat] ‘to cut’, and [k^{h}at] ‘to obstruct’. These (near) minimal pairs suggest that a contrast may exist between aspirated and unaspirated stops. However, most, if not all, linguists working on Khmer have argued against this analysis. The most common interpretation is that these aspirated stops are not unit phonemes, but a stop + /h/ cluster (Henderson 1952, Huffman 1967, 1972, Pinnow 1980). That is, the aspiration [h] is treated as a phoneme in itself, and the stability or retention of [h] in the infixation process (e.g., [k^{h}əŋ] ‘to be angry’ > [kɒmhəŋ] ‘anger’) is cited as the main argument for this analysis. /c/ is pronounced as a palatoalveolar affricate [t̠ɕ]. Aspirated [t̠ɕ^{h}] can be found to contrast with [t̠ɕ] as in [t̠ɕap] ‘to hold’ vs. [t̠ɕ^{h}ap] ‘fast’. However, similar to aspirated stops, it is treated as a stop /c/ + /h/ cluster. /b/ and /d/ are often pronounced as voiced implosives /ɓ/, /ɗ/. Labio-velar approximant /w/ is sometimes heard as voiced labio-dental fricative [v].

2.2 *Khmer vowels*

The Khmer vowel system according to Huffman (1978a) is shown in Table 2. In this categorization, a diphthong is defined as a complex nucleus in which the first element is a high vowel.

Table 2. Khmer vowels (from Huffman 1978a).

	First register			Second register		
Long						
	əj	əɨ	ou	iː	ɨː	uː
	ei	aə	ao	eː	əː	oː
	ae	aː	ɒː	ɛː	iə	ɔː
Short						
	e/ə		o	i/ɨ		u
	a		ɒ	ĕə/ŏə/ ɔ̆ə		ŭə
Diphthongs						
	iə	ɨə	uə	iə	ɨə	uə

2.3 Khmer word structure (Huffman 1970).

Khmer words under investigation in this study were monosyllabic of the $C_1rV(V)(C)$ structure. However, to understand the scope of the sound changes to be described, a brief outline of Khmer word structure is included here.

Monosyllables. Monosyllables in Khmer are of $C_1(C_2)(C_3)V_1(V_2)(C_4)$ structure. If V_2 does not occur, then C_4 must occur. In other words, in stressed syllables, short vowels must be followed by a consonant. Thus, monosyllables with a short vowel or diphthong will have one of the following three structures and the third one is rare.

1. CVC	/bət/	'to close'
2. CCVC	/sdap/	'to listen'
3. CCCVC	/sthət/	'to be located'

Monosyllables containing a long vowel or diphthong occur in the following five shapes; the fifth is rare.

1. CVV	/kaː/	'work'
2. CVVC	/baːn/	'to have'
3. CCVV	/chɨː/	'to be ill'
4. CCVVC	/craən/	'much'
5. CCCVVC	/sthaːn/	'place'

Disyllables. Minor disyllables consist of an unstressed (minor) syllable of the shape CV+, CrV+, CVN+, or CrVN+, followed by a stressed (major) syllable. In minor disyllables, the vowel of the unstressed syllable is usually reduced to /ə/ in casual speech. Words containing minor disyllables (i.e., one minor syllable followed by one major syllable) are also called "sesquisyllabic" (Matisoff 1973).

Examples: CV+ S	/kɒ.kaːy/	'to scratch about'
CrV+S	/prɒ.kan ~ prə.kan ~ pə.kan/	'to object'
CVN+ S	/bɒŋ.kaət ~ bəŋ.kaət ~ pə.kaət/	'to originate'
CrVN+S	/pram.bəj ~ prəm.bəj ~ pəm.bəj/	'eight'

Major disyllables consist of two stressed syllables in close juncture. Most of them are compounds.

Examples: /siəw.phɨw/	~ /se.phɨw/	'book'
/phiə.saː/		'language'
/buəŋ.suəŋ/		'to pray'
/sduəc.sdaəŋ/		'insignificant'

Polysyllables. Polysyllables are rare in colloquial speech, and usually are loan words from Pali, Sanskrit or French. Words of up to six syllables may occur in formal speech, and even longer words may occur in written text.

Examples:	Three syllables: /thŏəm.mə.daː/	'usually'
	Four syllables: /put.tə.sah.snaː/	'buddhism'
	Five syllables: /riəc.rŏət.thaː.phi.baːl/	'royal government'
	Six syllables: /wi.caː.rə.naʔ.kə. thaː/	'editorial'

3. Previous reports on tone development and other sound changes in Khmer

Noss (1968) and Huffman (1967) reported on a sound change involving a shift from syllable initial /r/ to /h/ in colloquial Khmer spoken in Phnom Penh. This shift was reported to be accompanied by a low-rising pitch. More recently, Pisitpanporn (1999) found that this shift had spread to other provinces as well, possibly due to the resettlement of Phnom Penh residents into those provinces during the Khmer Rouge regime. Interestingly, he found that in some provinces, together with the development of a falling-rising pitch due to the loss of an alveolar trill /r/, onglides were lost ([srae] > [sɛ̌ː] 'rice paddy'), and monophthongs became diphthongs ([krah] > [k^{h}ĭah] 'thick'). Moreover, he reported that among the younger generation, the falling-rising pitch was heard without the shift from /r/ to /h/ (e.g., [baː rəy] > [baː rə̌y]). Although not discussed, aspiration of the initial consonant and short vowel lengthening were also included (as shown in his transcription of the data) among the changes accompanying the loss of the trill /r/ (e.g., [pram] > [p^{h}ăːm] 'five') in some dialects.

Thach (1999) reported on a sound change in dialects of Khmer spoken in Vietnam in which consonant + /r/ clusters in onset position of main syllables lose the /r/ and gain a falling tone on the following vowel (e.g., [krɒː] > [kɒ̀ː] 'poor'). The sound change is quite advanced in these dialects, especially among younger speakers. Through this sound change, tone has been introduced and there are now minimal pairs such as [kɒ̀ː] 'poor' (from [krɒː]) and [kɒː] 'neck'. Additionally, Thach (1999) reported that the trill /r/ has become a glottal fricative /h/ in syllable initial position in main syllables.

From these earlier studies, we may conclude that sound changes associated with the loss of initial alveolar trill /r/ include the development of a falling or a falling rising pitch, a vowel quality shift as well as aspiration of the obstruent in the obstruent + /r/ initial. These changes only occur in colloquial pronunciation. These sound changes were reported without supporting acoustic evidence. Moreover, no phonetic explanation has been provided for them. These are thus the goals of this current study.

4. The current study

The goal of this study is to provide acoustic evidence to support the existence of the above sound changes in colloquial Khmer and more importantly to provide a plausible phonetic explanation for these changes. In this study, two speakers of Khmer from Phnom Penh were recorded saying *meaningful monosyllabic words with an obstruent + [r] cluster onset.* For comparison, both colloquial and reading pronunciations of the target words were elicited. To a large extent, the acoustic analyses confirmed the existence of the above sound changes, particularly the development of the falling-rising pitch accompanying the loss of /r/ in colloquial pronunciation. This finding is important as it may be taken as evidence for a possible new tonogenetic mechanism. We proposed that this mechanism is phonetically motivated.

5. Proposal for a new tonogenetic mechanism

Several mechanisms have been proposed to account for the origin of tones in a tone language. These include merger or loss of final consonant (e.g., Haudricourt 1954), vowel height, vowel duration (e.g., Svantesson 2001) and voice quality or phonation type contrast (e.g., Diffloth 1982,1989; Thurgood 2002). However, the most commonly reported tonogenetic process is the merger of voiced and voiceless onset consonants. When this occurs, a relatively lower pitch register develops on vowels following the previously voiced series while a relatively higher pitch develops on vowels following the previously voiceless series. This phenomenon has been attested widely in Southeast Asia (Hombert 1978 and references therein).

An aerodynamic phonetic account has been offered to explain the effect of onset consonant voicing on tone development. Specifically, it was proposed that voicing during a voiced stop closure leads to a decrease in transglottal pressure drop, thus a lower rate of airflow at the time of release. A lower rate of airflow results in a weak Bernoulli effect, hence a lower rate of vocal fold vibration (F_0) at vowel onset. On the other hand, a lack of voicing during the closure of a voiceless consonant increases transglottal pressure drop and thus a higher rate of airflow at the time of release. In turn, a higher rate of airflow induces a strong Bernoulli effect, and thus a higher F_0 (Hombert 1978) at vowel onset. When voicing distinction of the onset was lost the differential F_0 onsets could be phonologized as low and high tones.

The aerodynamic view on tone development was, however, challenged by some researchers. Ohala (1978), for example, pointed out that the differing aerodynamic effects on voiced and voiceless consonants only last for a few milliseconds, whereas the F_0 effects reported for voicing distinctions last for over 100 ms. Moreover, he observed that subglottal pressure actually builds up after the release of a voiced stop, but decreases after the release of a voiceless aspirated stop. Thus, the F_0 following voiced stops should actually be higher than that following voiceless aspirated stops. Ohala's observation was consistent with the finding reported in Klatt, Stevens & Mead's (1968) study. These researchers found a slightly higher volume of airflow for a short duration after the voiceless aspirated stops than after voiced stops. Additionally, Ohala and Sprouse (2003) reported that perturbing the transglottal pressure drop by venting pharyngeal pressure did not affect the F_0 of the following vowel.

An alternative view has been proposed that voiceless stops are produced with a greater tension on the vocal folds. This greater tension would serve to raise F_0 as vocal fold tension is positively related to rate of vocal fold vibration. The greater tension may be the result of laryngeal height (Ohala 1978 and references therein) or it may be due to constriction of the cricothyroid muscle (Löfqvist et al. 1989).

The consonantal environment conditioning the tone development and other accompanying sound changes in Khmer is different from those discussed above. As mentioned, these changes occur only in colloquial pronunciation of words with an apical trill /r/ or an obstruent + /r/ onsets. To reiterate, these changes include (a) the development of a falling-rising pitch contour, (b) aspiration of the initial obstruents and (c) the diphthongization of (low) monophthongs. We hypothesize that these changes were conditioned by the apical trill /r/ and the aerodynamic requirement during the production of the apical trill may offer a possible explanation.

To account for the development of the falling-rising pitch contour and the aspiration of the initial obstruents, we begin by hypothesizing that there is a greater fall in F_0 at word onset for vowels following a stop + /r/ cluster onset than for vowels following a single stop onset. This is due, perhaps, to the high volume of airflow needed for the production of the trill /r/. The high airflow conditions a high F_0 during the trill and creates a greater overall fall at word onset for CrV than CV words. A recent study by Guion and Wayland (2003) provided preliminary support for this hypothesis. In this study, oral airflow and F_0 measurements were obtained from five native Thai speakers producing nine (near) minimal quadruplets in Thai of $C_1V(V)(C)_2$, $C_1rV(V)(C)_2$, $C_1^hV(V)(C)_2$ and $C_1^hrV(V)(C)_2$ syllables structures where C_1 was either a bilabial, alveolar, or a velar stop and C_2 was always a sonorant. The results obtained showed that there was a greater drop in F_0 from onset of the voiced portion of the trill /r/ to the rime midpoint in syllables with onset + /r/ clusters than in syllables with onsets consisting of the same stop types without the /r/ (i.e., $C_1rV(V)(C)_2 > C_1V(V)(C)_2$; and $C_1^hrV(V)(C)_2 > C_1^hV(V)(C)_2$). Similar patterns of results were found for oral airflow data.

Guion and Wayland (2003) suggested that the falling of F_0 could be reinterpreted as a falling tone if the trill was lost or weakened to voiceless trill or aspiration. That is, the falling pitch contour resulting from a drop in airflow volume during the voiced trill into the vowel failed to be corrected by Khmer listeners associated with the following vowel after the trill was lost; a phenomenon that often occurs due to a difficulty in maintaining a delicate aerodynamic balance required to sustain voicing during a trill production especially in a faster colloquial speech (McGowan 1992[1]; Solé 2002).

An increase of airflow after vowel onset could then perhaps serve to increase the F_0 toward the end of the syllable thus creating the reported overall falling-rising pitch contour. However, no aerodynamic data is available to support this hypothesis at present. As such it should be taken with caution until further experimental data becomes available.

The diphthongization of monophthongs could stem from the coarticulatory effects of the trill on the following vowels. That is, depending perhaps on the differences in degrees and location of the oral constriction aperture (or tongue body height) between the trill and the following vowels, a low or high on-glide from the trill to the beginning of the following vowels may be heard. Since the difference in the size and location of the oral constriction will be greatest between the trill and the low vowels, the resulting high front onglide from the trill to the low vowels may be relatively more salient. This high front on-glide could then be reanalyzed by the listeners as a high vowel (or any front vowel that has a higher quality than the low vowel in question.)

In summary, we propose the following to account for the reported sound changes in Khmer. (1) A high rate of airflow needed for the production of the voiced alveolar trill /r/ would produce a comparatively greater drop in F_0 at vowel onset. If the voiced alveolar trill /r/ became voiceless in a faster colloquial pronunciation, the falling F_0 contour could becomes associated with the following vowel. (2) An increase in airflow after the onset of the vowel could give rise to the observed rising part of the falling-rising contour. (3) The voiceless trill /r/ could also be heard as aspiration of the initial obstruent. (4) The lingual coarticulatory effect of the trill /r/ on the following vowel could become associated with the beginning of the following low vowels causing low vowels to become diphthongized.

6. Acoustic analysis

The goal of this analysis is to provide acoustic evidence in support of the reported sound changes in Khmer, as well as the phonetic explanation just described above. To this end, an acoustic analysis of a subset of words undergoing these changes are examined.

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[1] Insufficient pressure difference across the lingual constriction during trill initiation (as may occur in fast colloquial speech) may also result in the trill being produced as a fricativized trill. This could then explain the change from /r/ to /h/ in absolute initial position reported in Pisitpanporn (1999).

6.1. Method

Speakers. Two male native speakers of Khmer from Phnom Penh served as speakers. They are designated as speakers PP1 and PP2. At the time of recording, PP1 was 32 years old and had been living in the US for 4 months. PP2 was 26 years old and had been living in the US for 1 year.

Stimuli. Stimuli were 20 lexical items (see Appendix A) beginning with an obstruent-/r/ cluster. Of these, 13 words began with a voiceless stop consonant, three with a voiceless affricate and four with a voiceless fricative. All stimuli were recorded in a quiet room in a library in Portland, Oregon, using a portable DAT recorder at a 44.1 kHz. sampling rate, and a high quality head-mounted microphone (Shure SM 10A) placed at a 45 degree angle 15 cm from the speaker's mouth to prevent a high turbulent flow directly to the microphone.

The speakers were instructed to say the target words in a carrier phrase ខ្ញុំថា________________ទៀត [kʰɲom tʰaː ________tiət] "I say _____again." at a normal speaking rate. Both the carrier phrase and the target words were written in Khmer orthography. The use of a carrier phrase was important to the methodology as it provided a consistent prosodic environment. For comparison purposes, the speaker was instructed to first say the word as they normally would if they were to read it from a book (spelling or reading pronunciation), and second as they would in a conversation to another Khmer speaker (colloquial pronunciation). Each word was produced three times in each of the two speech styles.

The speakers readily understood the task and were able to perform it with ease. PP1's production was at a faster pace than that of PP2's.

Procedure. The recordings were digitally transferred to a PC and down sampled to 22050 Hz using a Kay Elemetrics CSL (Model 4400). Each word was edited and stored as a separate file, and subsequent acoustic analyses were performed using Kay Elemetrics CSL (4400) analysis package. Acoustic measurements included voice-onset-time (VOT) for words with stop initials, frication duration for words with affricate initials, vowel fundamental frequency (F_0) and frequencies of the first and second formants (F1, F2). Prior to any acoustic measurements, tags were added to the waveform of each target word at vowel onset, 20% into the vowel, vowel mid-point, 80% into the vowel, and vowel offset.

For reading pronunciation (i.e., with the alveolar trill /r/), vowel onset was taken to be the location where the trill ends, which typically coincides with the location where the overall amplitude of the formant increases as shown in both the waveform and the corresponding spectrogram (Figure 1). Care was taken to place all cursors at zero crossing on the waveform. In some cases, especially in tokens spoken by PP2, the alveolar trill /r/ was partially devoiced and trilling motion was not maintained throughout its duration. In this case, cursors were placed as shown in Figure 2 and vowel onset was taken to be the onset of voicing (periodicity) after the voiceless trill.

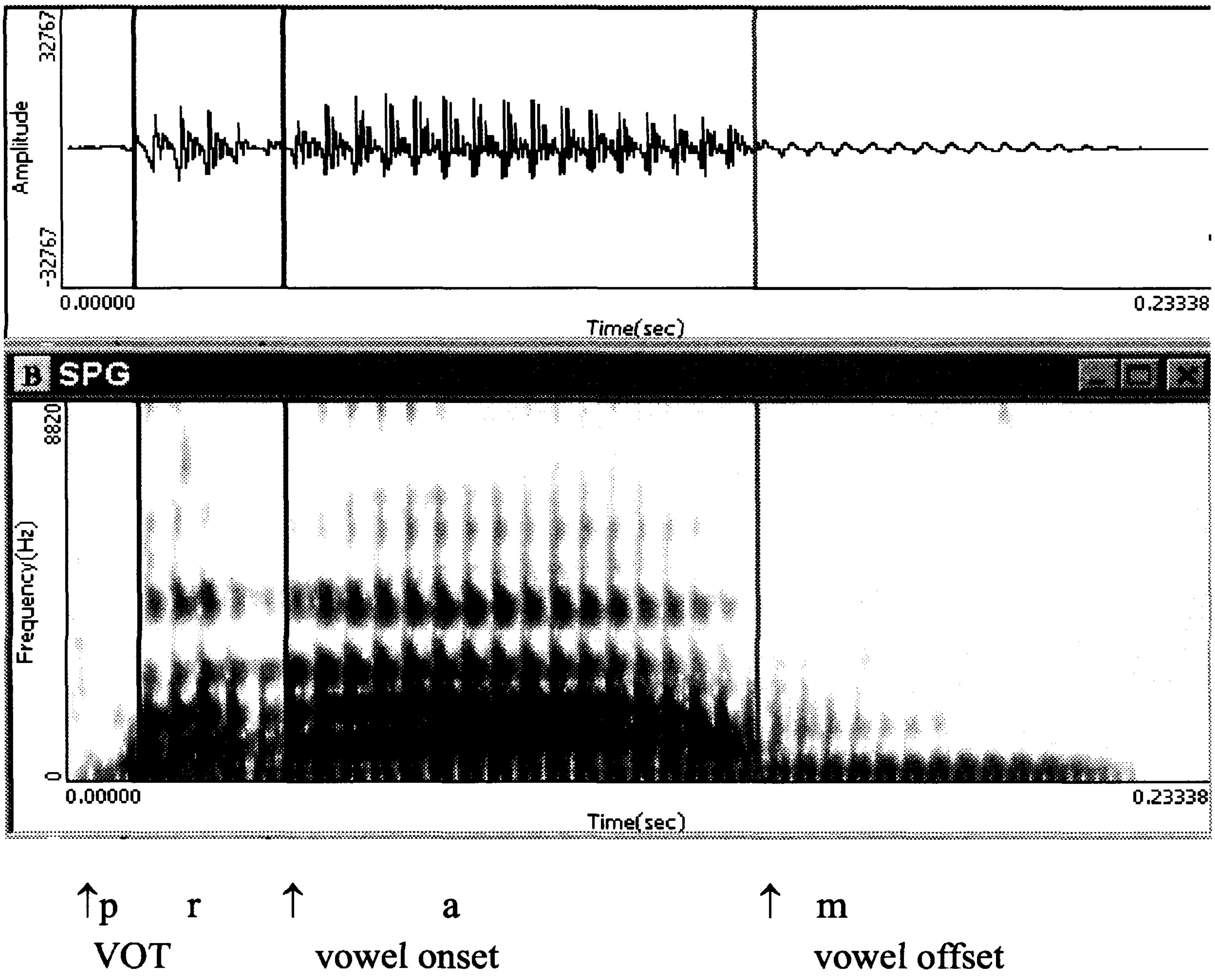

Figure 1. Spectrogram of ប្រាំ 'five' spoken by PP1.

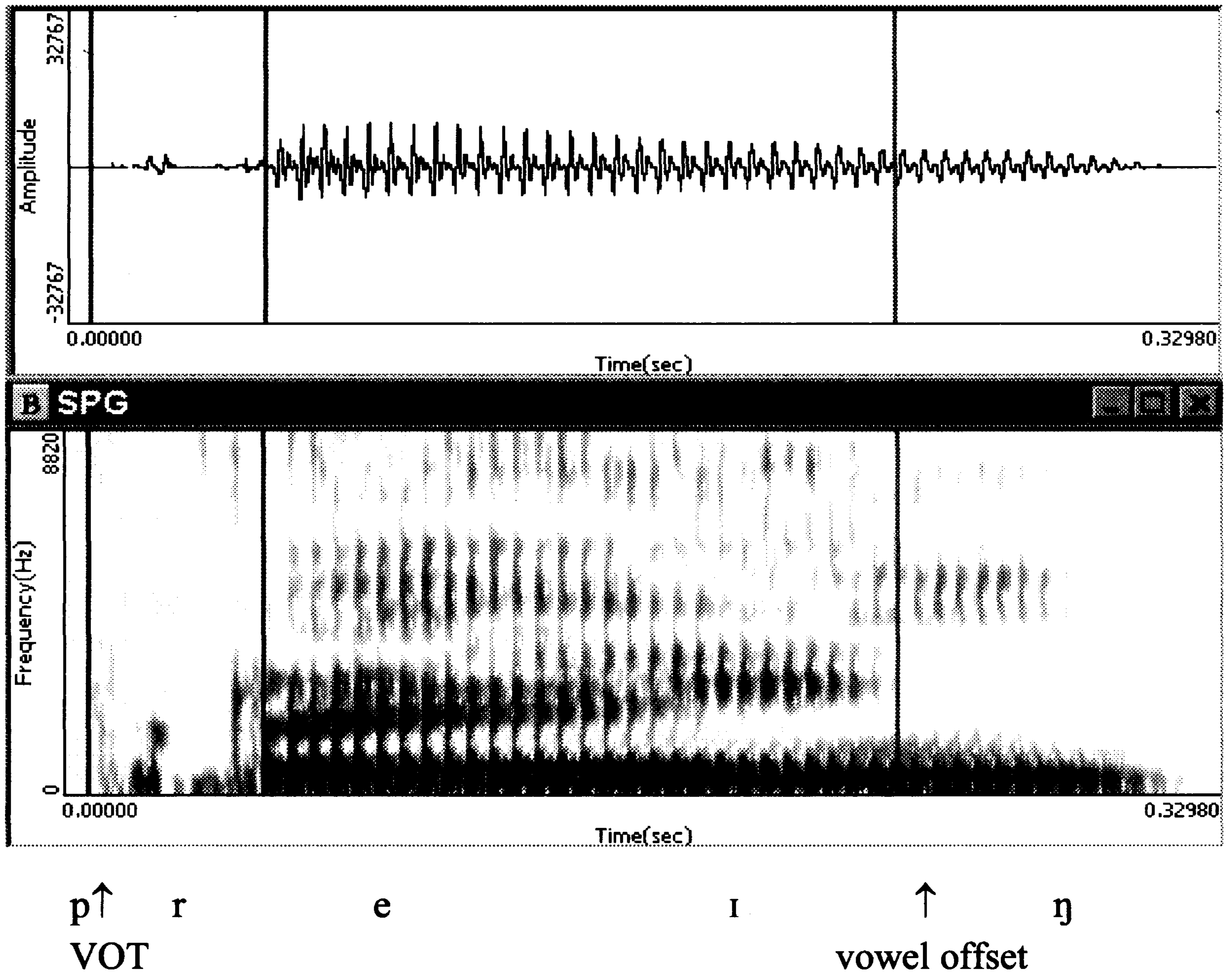

Figure 2. Spectrogram of ព្រេង 'fortune' spoken by PP2.

For tokens produced with colloquial pronunciation, vowel onset was considered to be the onset of periodicity (Figure 3).

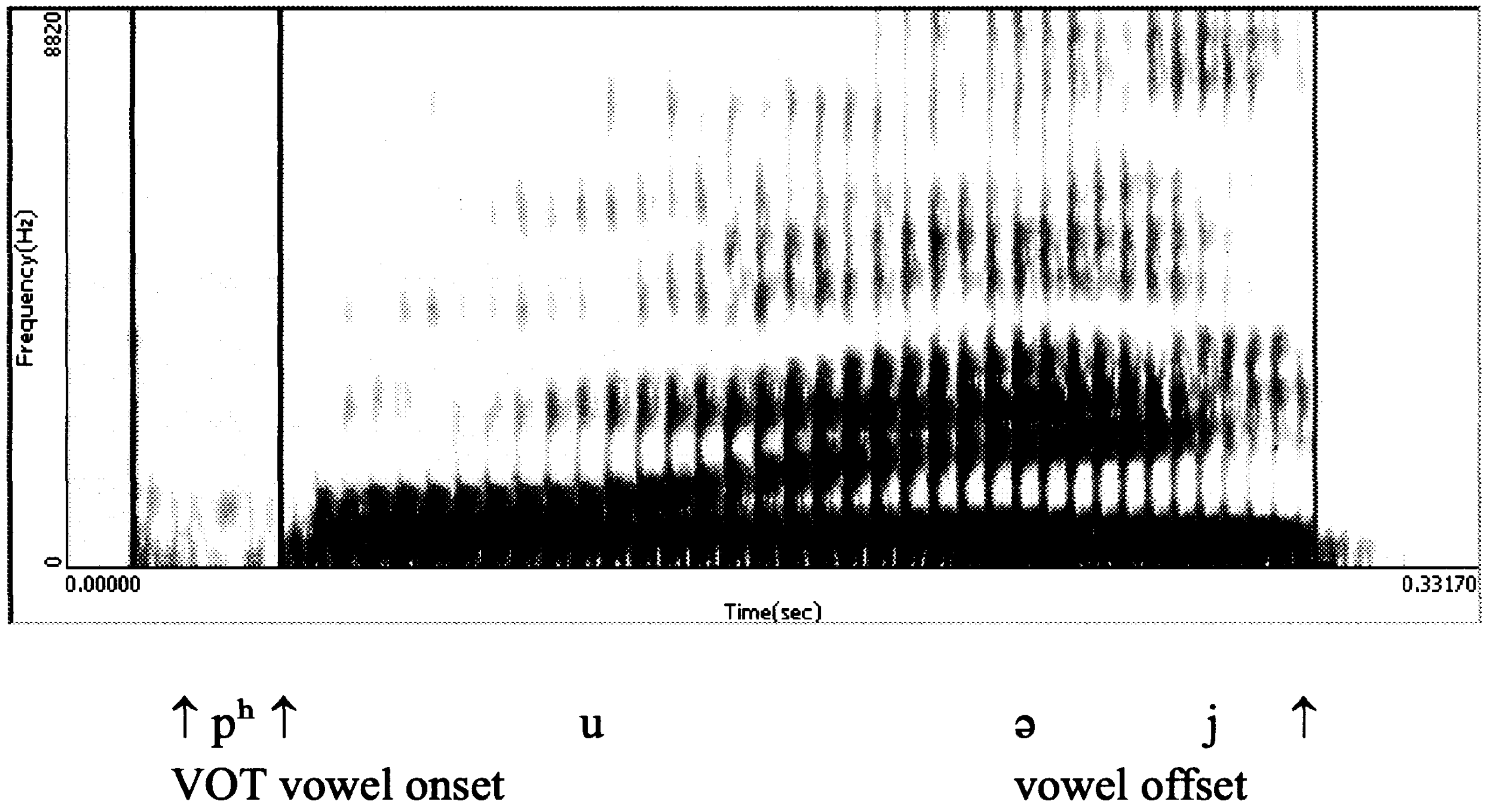

Figure 3. Spectrogram of ព្រួយ 'sad' in colloquial pronunciation spoken by

For both types of pronunciation, in open-syllable contexts, vowel offset was considered to be the location where F2 ceased to be clearly visible on the spectrogram (Figure 3). In closed-syllable contexts with a stop as the final consonant, vowel-offset was taken to be the offset of F2 prior to the final stop closure (Figure 4). In nasal final contexts, vowel-offset was considered to be the location where waveform and formant amplitudes drastically decreased due to anti-resonances (Figure 1, 2).

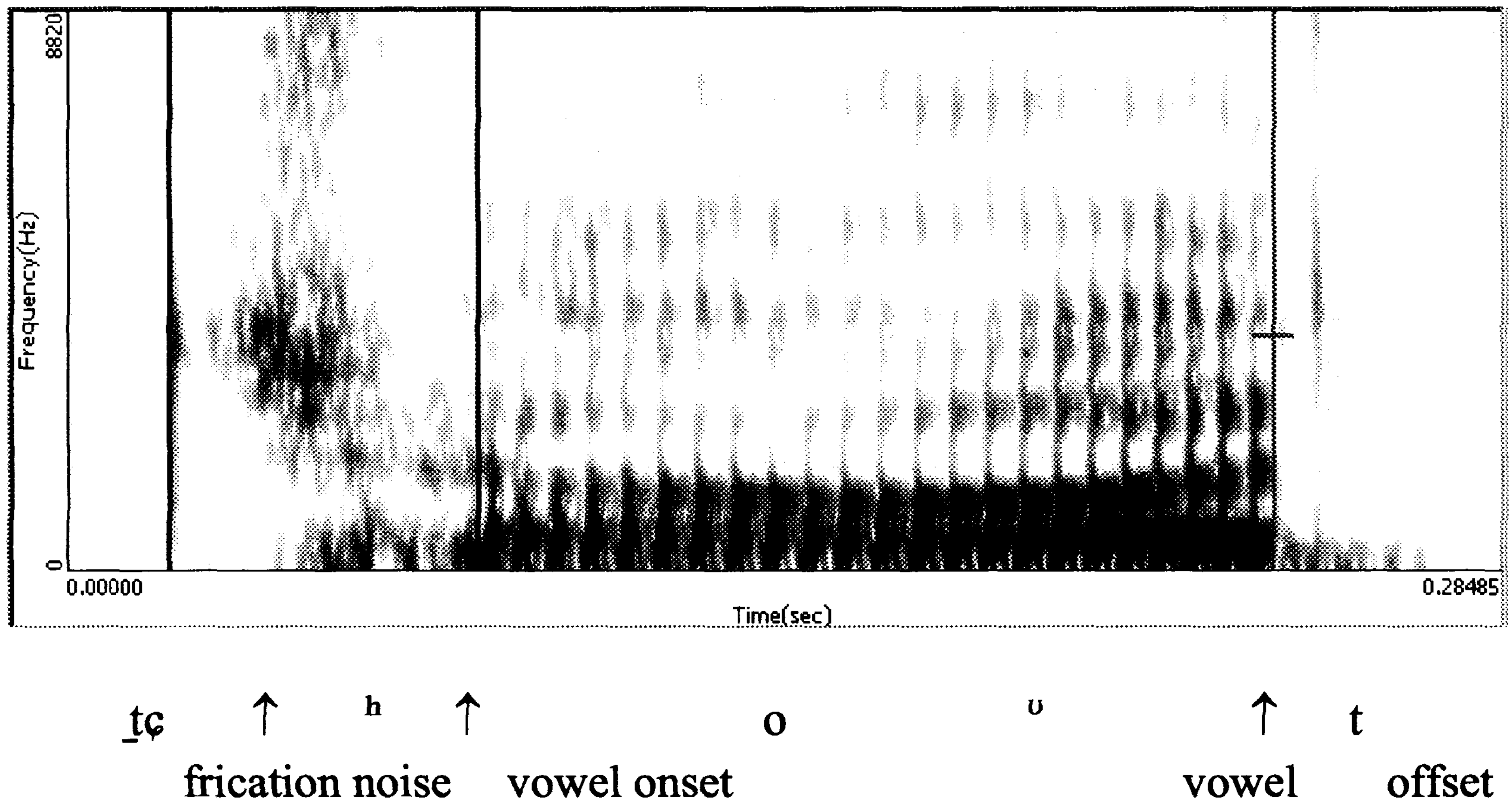

Figure 4. Spectrogram of ច្រូត 'harvest' in colloquial pronunciation spoken by PP2.

VOT was measured from the release burst to the onset of the voiced or voiceless trill (Figure 1 and 2) for reading pronunciation and to onset of voicing (Figure 3) for colloquial pronunciation. Similarly, frication duration in voiceless affricates was measured from the release burst to voicing onset in case of colloquial pronunciation (Figure 4) and from the release burst to the onset of the trill (Figure 5).

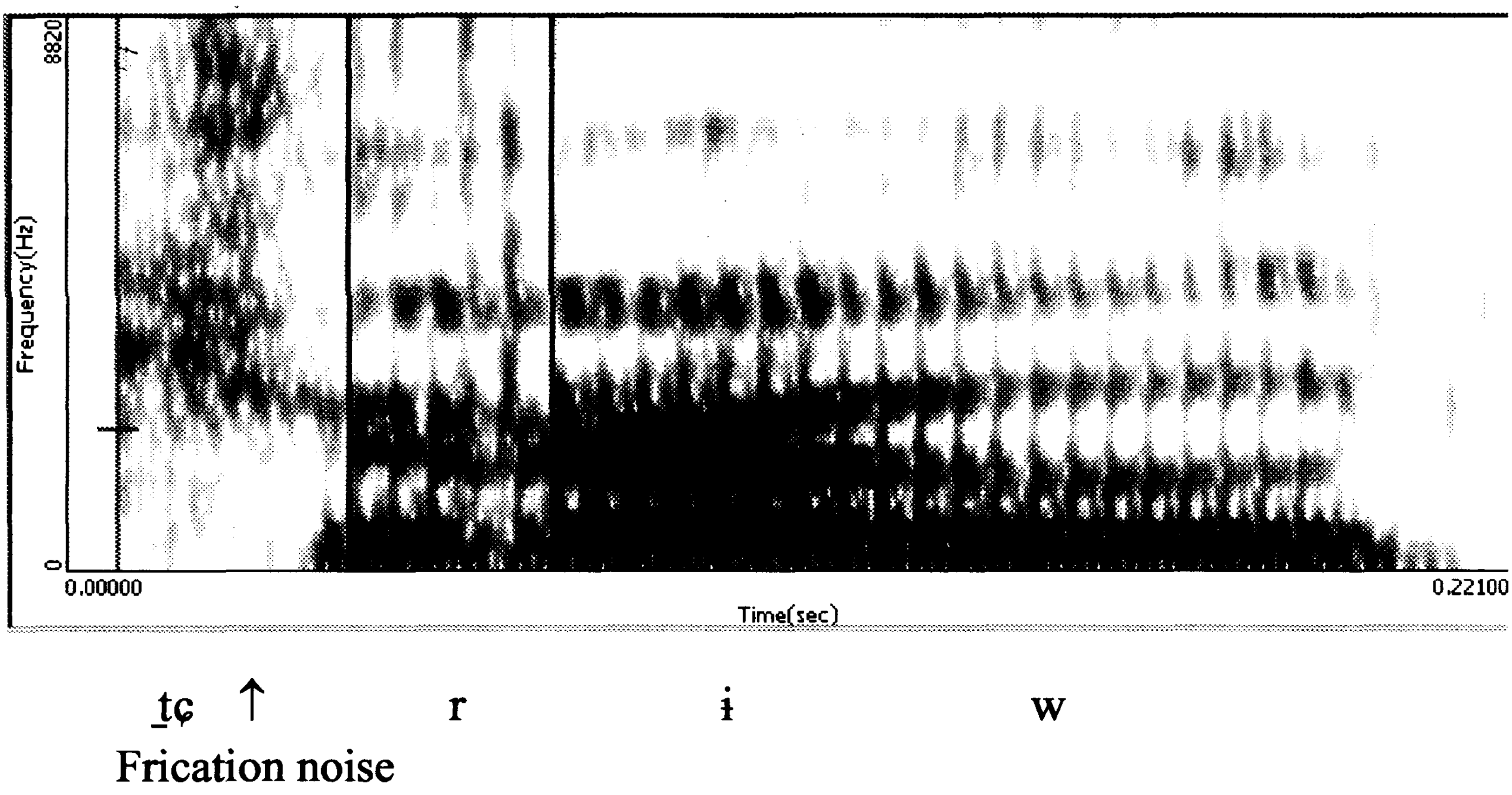

Figure 5. Spectrogram of ជ្រៅ 'deep' in reading pronunciation spoken by PP1.

To measure F_0, impulse marks were manually inserted into the waveform. F_0 contour for each vowel was then generated by computing the inverse of the time between each impulse mark using CSL (4400). F_0 values were then measured at five different locations in the vowel, namely at vowel-onset, 20% into the vowel, vowel mid-point, 80% into the vowel and at vowel-offset.

Vowel formant frequencies (F1 and F2) were measured for all tokens. F1 and F2 values at 20% and 80% in the vowels were obtained from LPC spectra (25 ms Hamming window and 24 coefficients).

6.2. Results

Fundamental Frequency Contour. F_0 contours (in Mels) for colloquial and reading pronunciation averaged across all words for both PP1 and PP2 are illustrated in Figure 6 and 7.

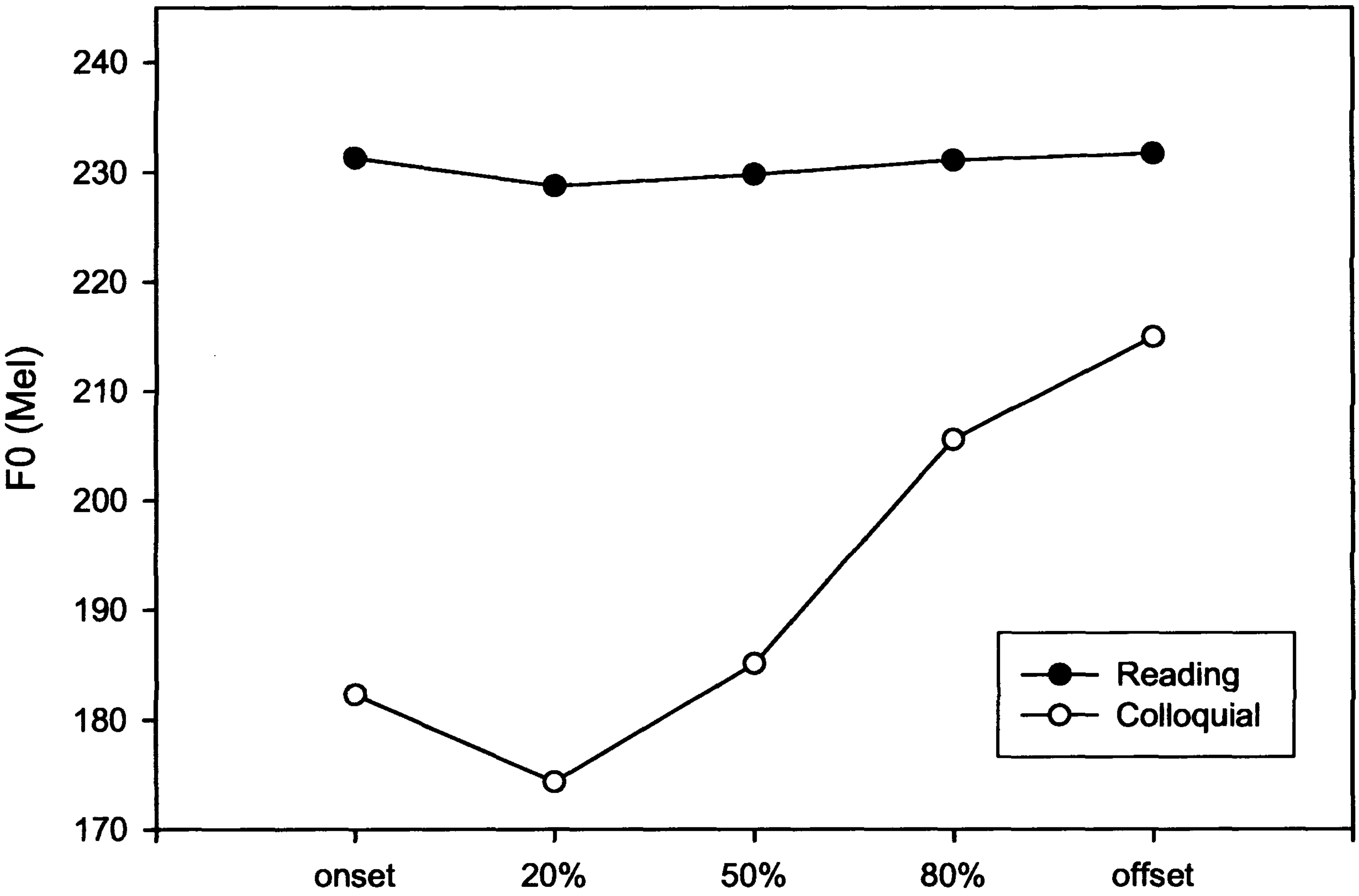

Figure 6. Normalized F_0 contours for colloquial and reading pronunciations for PP1.

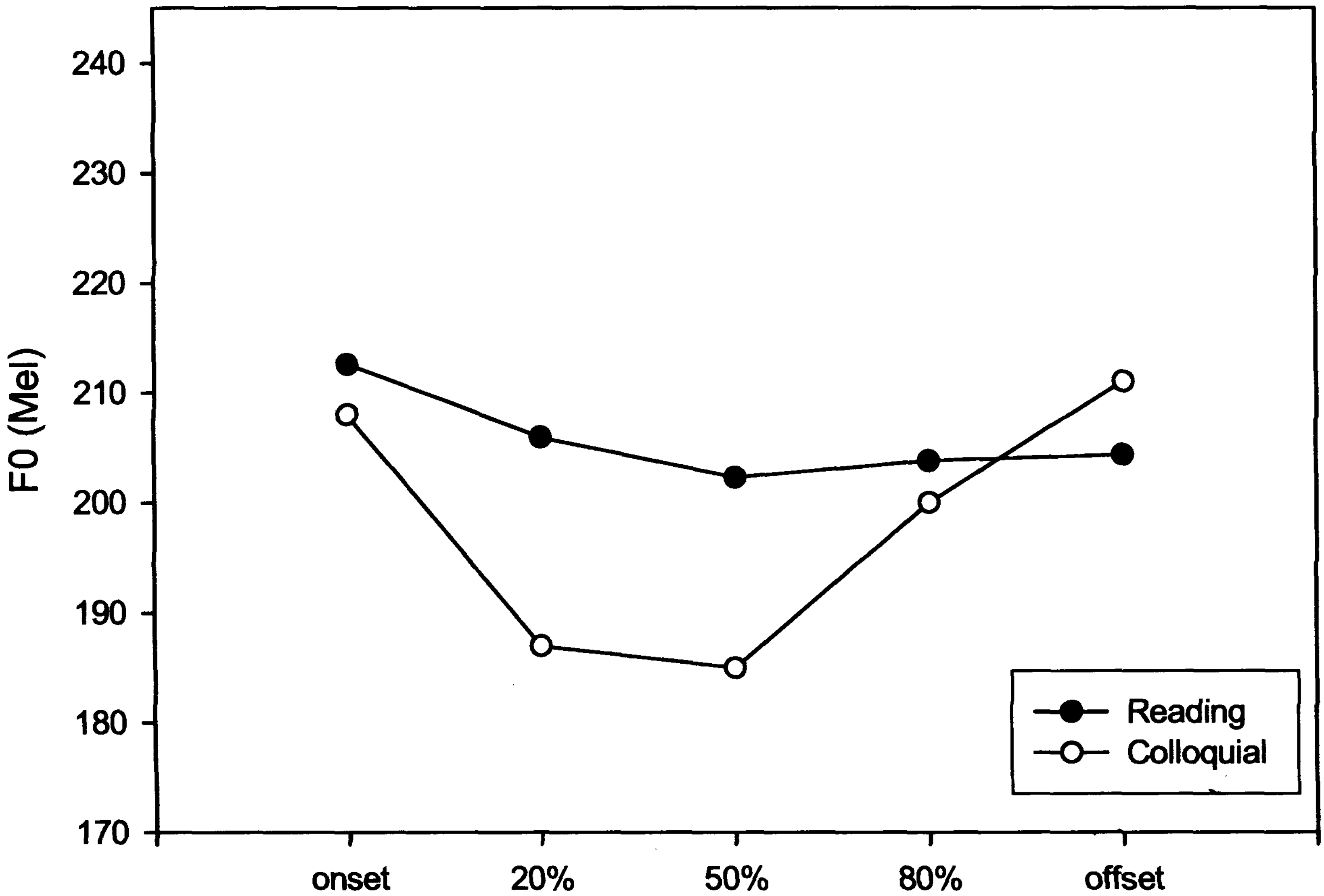

Figure 7. Normalized F_0 contours for colloquial and reading pronunciations for PP2.

For speaker PP1 (Figure 6), it is obvious that F_0 values at all five locations in the vowel were higher in reading than in colloquial pronunciation. In colloquial pronunciation, F_0 values at 20% into the vowel dropped before starting and continuing to rise toward the end of the vowel. Thus, while a high-level pitch contour best characterizes reading pronunciation, a falling-rising contour best characterized colloquial pronunciation for this speaker.

A falling-rising contour is also the characteristic of PP2's colloquial pronunciation (Figure 7). For this speaker, F_0 values at both vowel onset and vowel offset are comparable in both types of pronunciation. However, F_0 value begins to drop at 20% into the vowel and continue to decrease at the center of the vowel before it begins and continues to rise toward the end of the vowel.

First, a statistical analysis of the F_0 data for PP1 is presented, then an analysis of PP2. A mixed designed ANOVA with Style (colloquial vs. reading) as the repeated factor and Position (onset, 20%, 50%, 80%, offset) as the between subject factor on the mean (of 3 repetitions) F_0 values (in mels) for PP1 returned a significant main effect of Style [$F(1,95) = 1565.65$, $p <.001$) and Position [$F(4,95) = 25.76$, $p <.001$] as well as a significant interaction [$F(4,95) = 56.29$, $p <.0001$]. Tests of simple main effect revealed that the effect of Position was found for colloquial mode of reading only [$F(4,156) = 67.59$, $p <.001$]. On the other hand, simple main effect of Style was found for all five positions [$F(4,95)$ ranging from 60 – 639.7, $p <.001$].

A further investigation of the interaction was conducted by performing a one-way ANOVA comparing F_0 values in all five positions in colloquial pronunciation. As expected, the analysis yielded a significant effect of Position [$F(4,95) = 47.68$, $p <.001$]. Post-hoc pair-wise comparison showed that F_0 values at vowel onset were significantly lower than those at 80% and at vowel offset [Bonferroni adjusted $p <.001$]. Moreover, F_0 values at 20% into the vowel was found to be significantly lower than those at vowel mid-point, 80% into the vowel and at vowel offset [Bonferroni adjusted p values ranging from .03 to .0001]. F_0 values at vowel midpoint were lower than those at 80% and at vowel offset [Bonferroni adjusted $p <.001$], and F_0 values at 80% into the vowel were also lower than those at vowel offset [Bonferroni adjusted $p <.001$].

These results suggest that, for PP1, there was a significant rise in F_0 from 20% into the vowel all the way to vowel offset. The non-significant difference in F_0 values at vowel onset and at 20% into the vowel may have been related the overall faster speech rate of this speaker. As will be reported below, the difference in F_0 values at these two locations in the vowel was significantly different in PP2 whose over all speaking rate was slower than that of PP1.

Similar analyses were performed for the F_0 data obtained for PP2. Results of the mixed-designed ANOVA showed a significant main effect of a significant interaction [$F(4,95) = 20.61$, $p <.001$]. Simple main effect tests revealed that the effect of Position was significant for both reading and colloquial modes of pronunciations and the effect of Style on F_0 values was significant for all but one of the positions (i.e., 80% in the vowel).

Further investigation of the interaction was conducted by performing a one-way ANOVA on F_0 values for each speaking style separately. As expected, the analyses yielded a significant effect of Position for both styles [$F(4,950) = 29.05$ and 8.27, $p <.001$]. Post-hoc pair-wise comparisons showed that for colloquial pronunciation, F_0 values at vowel onset were significantly higher than those at 20% into the vowel and at vowel midpoint [Bonferroni adjusted $p <.001$]. Moreover, F_0 values at 20% into the vowel were significantly lower than those at 80% into the vowel and at vowel offset [Bonferroni adjusted $p <.001$ respectively]. F_0 values at vowel midpoint were significantly lower than those at 80% into the vowel and at the end of the vowel [Bonferroni adjusted $p <.001$]. Finally, F_0 values at 80% into the vowel were significantly lower than those at vowel offset [Bonferroni adjusted $p <.006$].

These results clearly suggest a falling-rising pitch contour in colloquial pronunciation for this speaker. On the other hand, his reading pronunciation exhibited a falling pitch contour. Post-hoc pair-wise comparison showed that F_0 values at vowel onset were significantly higher than those of other positions in the vowel [Bonferroni adjusted p values ranging from $<.0001$ to $.01$]. No other significant pair-wise result was obtained.

Note that the finding of a falling-rising pitch contour is in agreement with Pisitpanporn's (1999) finding, but somewhat different from the Khmer dialect spoken in Vietnam reported in Thach (1999). Perhaps the falling tone reported for this dialect was a description of the falling part of the contour, or perhaps the tone development is different in the two dialects of Khmer. An acoustic investigation of the Khmer dialect spoken in Vietnam would need to be undertaken to decide the matter.

Voice Onset Time. Mean VOT duration of initial stop consonants for both modes of pronunciation for PP1 is shown in Table 3, and those for PP2 is shown in Table 4. Overall, PP1's mean VOT for colloquial pronunciation was slightly shorter than that of PP2's. This could be due to the fact that PP1's pronunciation was faster overall than that of PP2's. For both speakers, VOT duration of initial stops in colloquial speech was longer than that of the reading pronunciation (mean = 51 vs. 12 ms for PP1 and 56 vs. 12 ms for PP2). Result of a paired t-test supported this observation ($t(12) = 14.86$, $p < 0.001$ for PP1, $t(12) = 9.17$, $p < 0.001$ for PP2). This finding confirmed that voiceless stop /p, t, k/ initials in reading pronunciation became aspirated in colloquial pronunciation.

Table 3. Mean VOT duration (in ms) and standard deviations (in parentheses) for stop initials in reading and colloquial modes of pronunciation for PP1.

word		colloquial	reading
/pram/	‘five’	39	15
/praə/	‘use’	42	13
/prap/	‘tell’	41	12
/pruəj/	‘sad’	41	9
/priəj/	‘spirit’	54	12
/proh/	‘male’	53	16
/trɨw/	‘correct’	49	9
/pre$^{\mathrm{I}}$ŋ/	‘oil, gas’	48	13
/pre$^{\mathrm{I}}$ŋ/	‘fortune’	54	8
/priep/	‘pigeon’	58	11
/kru/	‘teacher’	69	12
/krɒː/	‘poor’	63	13
/krŏən/	‘enough’	50	13
Mean		**51 (9.03)**	**12 (2.31)**

Table 4. Mean VOT duration (in ms) and standard deviations (in parentheses) for stop initials in reading and colloquial modes of pronunciation for PP2.

word		colloquial	reading
/pram/	‘five’	62	11
/praə/	‘use’	71	11
/prap/	‘tell’	82	9
/pruəj/	‘sad’	37	11
/priəj/	‘spirit’	48	9
/proh/	‘male’	64	14
/trɨw/	‘correct’	67	12
/preᶦŋ/	‘oil, gas’	37	12
/preᶦŋ/	‘fortune’	29	13
/priep/	‘pigeon’	34	11
/kru/	‘teacher’	69	11
/krɒː/	‘poor’	53	13
/krŏən/	‘enough’	69	13
Mean		**56 (16.9)**	**12 (1.5)**

Fricative Noise Duration. Mean fricative noise durations after the burst of a voiceless affricate initial in both styles for PP1 are shown in Table 5 and those for PP2 in Table 6. Similar to what we found for VOT, mean fricative noise duration in PP1's pronunciation was shorter than that of PP2's. As expected, for all three words, fricative noise duration was longer for colloquial than for reading pronunciation. This is true for both speakers (mean = 59 vs. 26 ms for PP1 and 68 vs. 18 ms for PP2). This difference was significant in a paired t-test on three repetitions of all three words ($t(8) = 12.50$, $p < .001$ for PP1, and $t(8) = 5.73$, $p < .001$). This finding suggested that a voiceless affricate /t̠ɕ/ in reading pronunciation became a voiceless aspirated affricate [t̠ɕʰ] in colloquial speech.

Table 5. Mean fricative noise duration (in ms) and standard deviations (in parentheses) of voiceless affricate /t̠ç/ in reading and colloquial pronunciation for PP1.

word		colloquial	reading
/t̠çroʊt/	‘harvest’	56	24
/t̠çrɨw/	‘deep’	57	26
/t̠çrŏəm/	‘muddy’	65	28
Mean		**59 (7.21)**	**26 (5.05)**

Table 6. Mean fricative duration (in ms) and Standard Deviations (in parentheses) of voiceless affricate /t̠ç/ in reading and colloquial pronunciation for PP2.

word		colloquial	reading
/t̠çroʊt/	‘harvest’	63	36
/t̠çrɨw/	‘deep’	69	10
/t̠çrŏəm/	‘muddy’	71	9
Mean		**68 (19.5)**	**18 (13.5)**

A Vowel Quality Change. F1 and F2 were measured at 20% and 80% into the vowel for all vowels of all tokens produced by both speakers. However, substantial differences in vowel quality between the reading and colloquial pronunciations were only found for the low vowels. Thus, only the data for the low vowels will be reported here. These findings confirm the reports in previous studies of diphthongization of low monophthongs and the loss of low onglides. The vowels under consideration are /a/, /aː/ and /ɒː/ and /ae/. Mean F1 and F2 values for these vowels in both reading and colloquial pronunciations are reported in Tables 7 and 8 for PP1 and in Tables 9 and 10 for PP2.

Table 7. Mean F1 and F2 values (in Hz) of low vowels in PP1's reading pronunciation.

Words		Reading pronunciation			
		F1 at 20%	F2 at 20%	F1 at 80%	F2 at 80%
/pram/	'five'	812	1657	886	1523
/prap/	'tell'	757	1309	834	1255
/praə/	'use'	863	1619	894	1624
/sraː/	'alcohol'	795	1125	867	1611
/krɒː/	'poor'	695	1052	752	1090
/sraek/	'shout'	699	1669	550	2154

Table 8. Mean F1 and F2 values (in Hz) of low vowels in PP1's colloquial pronunciation.

Words		Colloquial pronunciation			
		F1 at 20%	F2 at 20%	F1 at 80%	F2 at 80%
/pram/	'five'	591	2267	972	1728
/prap/	'tell'	560	2090	750	1770
/praə/	'use'	613	2092	854	1677
/sraː/	'alcohol'	477	2153	832	1750
/krɒː/	'poor'	562	942	720	1263
/sraek/	'shout'	532	2083	407	2334

An examination of Table 7 and 8 revealed that the formant values at 20% into the vowel were different than those at 80% into the vowel. In reading pronunciation (Table 7), low monophthongs (/a, aː, ɒː/) in /pram/ 'five', /prap/ 'tell', /sraː/ 'alcohol' and /krɒː/ 'poor' were higher (lower F1) at 20% into the vowel than at 80% into the vowels. This finding suggested that, due to its relatively higher degree of oral constriction, the preceding alveolar trill /r/ had the effects of raising the quality at onset of the following low vowels. Interestingly, however, this coarticulatory effect did not disappear after the /r/ was lost in colloquial pronunciation. On the contrary, it appeared to have been enhanced. This was indicated by lower F1 and higher F2 values at 20% into the vowel in Table 8 than in Table 7. In other words, low front unrounded vowel /a/ and /aː/ in /pram/ 'five', /prap/ 'tell', /praə/ 'use' and /sraː/ 'alcohol' in reading pronunciation became a diphthong /ea/ in colloquial pronunciation. (See Figure 8 and 9 for spectrograms of /prap/ 'tell' in both reading and pronunciations.) Similarly, low back rounded vowel /ɒː/ in /krɒː/ 'poor' in reading pronunciation became /ɔ^a/ in colloquial pronunciation. According to Pisitpanporn (1999), this vowel was pronounced [uːə] in one of the dialects he investigated. These findings suggested that the high onglides that resulted from the coarticulatory effect of the trill /r/ at onset of the following low vowels in reading pronunciation were perceptually reanalyzed (hypo-corrected) in colloquial pronunciation as non-low vowels causing the original low vowels to be heard as a diphthong.

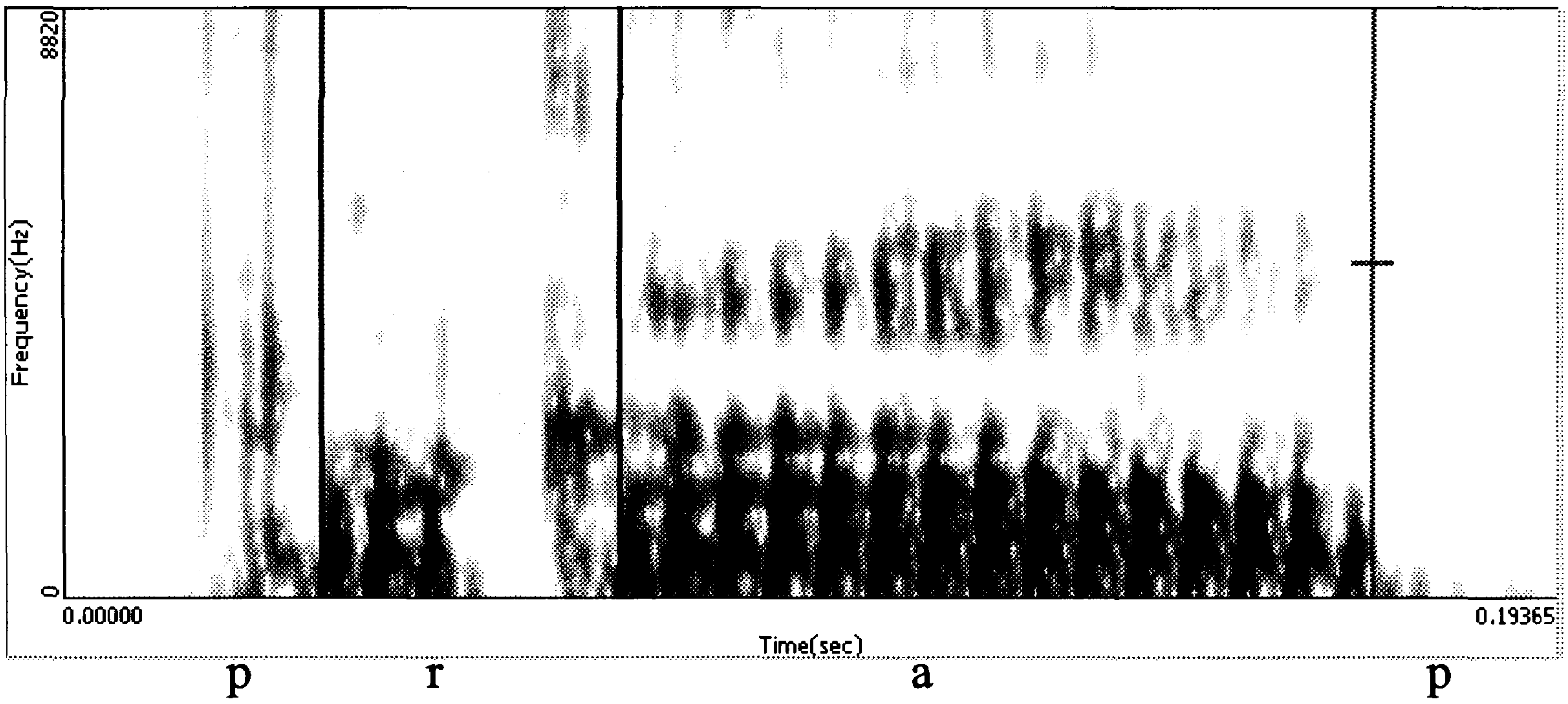

Figure 8. Spectrogram of ប្រាប់ 'tell' in PP2's reading pronunciation.

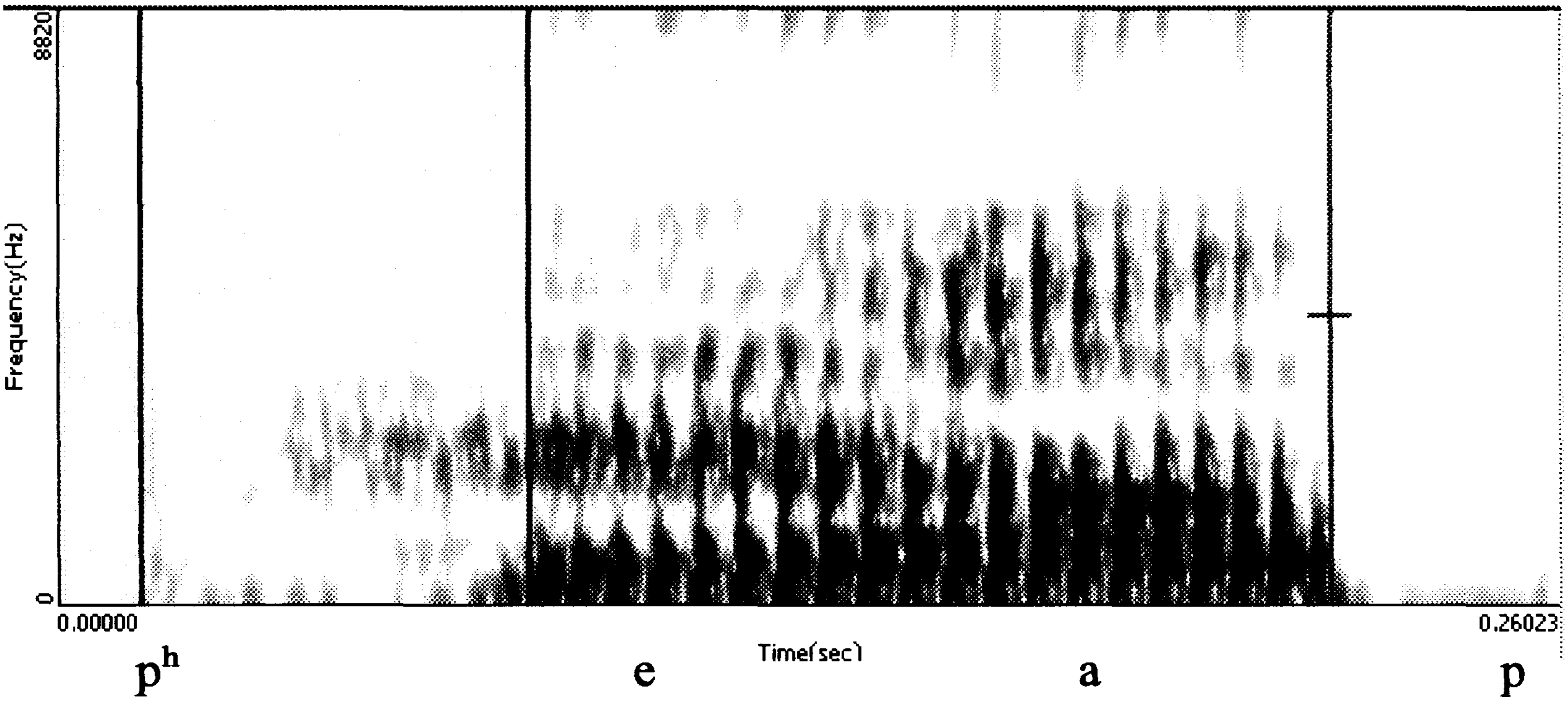

Figure 9. Spectrogram of ប្រាប់ 'tell' in PP2's colloquial pronunciation.

The enhancement of the coarticulatory effect of /r/ on the following low vowel /a/ was also observed when /a/ occurred as the low onglide or the first element of a diphthong as in /aə/ in /praə/ 'use' and /ae/ in /sraek/ 'shout'. F1 values at 20% into the vowel for /a/ in /aə/ and /ae/ were lower in colloquial pronunciation (Table 8) than in reading pronunciation (Table 7). As a result, /a/ in /praə/ 'use' became a diphthong /ea/. On the other hand, the raising and fronting of the low front /a/ in the diphthong /ae/ in /sraek/ 'shout' causing it to become more like /e/ thus reducing the degree of diphthongization. This change may be taken as evidence to support the existence of the monophthongization process reported in previous studies. According to Pisitpanporn (1999), this vowel was pronounced as [ɛː] in one of the dialects he investigated.[2]

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[2] This vowel was phonemically transcribed as /ae/ by Huffman (1978a). However, it was phonetically closer to [aɛ]. This may explain why /ae/ became /ɛː/ not /eː/ when /a/ was raised

An examination of F1 and F2 values obtained from PP2 (Tables 9 and 10) revealed that, similar to PP1, low vowels were relatively higher (lower F1) at 20% into the vowel than at 80% into the vowel in reading pronunciation. Also similar to PP1, this difference in vowel height (including /a/ in /aə/ 'use') was exaggerated in colloquial pronunciation. These changes caused low vowels /a/, /aː/ in

Table 9. Mean F1 and F2 values (in Hz) in PP2's reading pronunciation.

	Reading Pronunciation			
Words	F1 at 20%	F2 at 20%	F1 at 20%	F2 at 80%
/pram/ 'five'	658	1342	742	1382
/prap/ 'tell'	642	1521	714	1446
/praə/ 'use'	797	1528	679	1542
/sraː/ 'alcohol'	690	1429	764	1609
/krɒː/ 'poor'	549	1276	602	1163
/sraek/ 'shout'	691	1487	484	1864

Table 10. Mean F1 and F2 values (in Hz) in PP2's colloquial pronunciation.

	Colloquial Pronunciation			
Words	F1 at 20%	F2 at 20%	F1 at 20%	F2 at 80%
/pram/ 'five'	583	1929	786	1483
/prap/ 'tell'	541	1892	712	1453
/praə/ 'use'	682	1636	700	1486
/sraː/ 'alcohol'	476	1909	863	1382
/krɒː/ 'poor'	530	984	653	1291
/sraɛk/ 'shout'	578	1432	470	1751

F1 and F2 values at 20% and 80% into the vowels for PP2's reading and colloquial pronunciations are shown in Table 9 and 10. Similar to the data obtained from PP1, this data revealed that, low monophthongs /a/, /aː/ and /ɒː/ were higher (lower F1) at 20% into the vowel than at 80% into the vowel in reading pronunciation (Table 9). The difference was exaggerated in colloquial pronunciation (Table 10) causing these vowels (including the low onglide /a/ in /praə/ 'use') to become a diphthong /ea/. Also similar to PP1, the raising and fronting of /a/ in the diphthong /ae/ in /sraek/ 'shout' reduced its perceived degree of diphthongization. Unlike PP1 however, PP2's low back rounded vowel /ɒː/ in /krɒː/ 'poor' was phonetically [ɔ] in reading pronunciation. It became slightly more back (lower F2) in colloquial pronunciation but its height remained relatively unchanged. Similar to PP1, *this vowel could be transcribed as a diphthong [ɔ^{a}].*

In summary, the data reported in this section provided support for the diphthongization of low monophthongs reported in previous studies. Suggestive acoustic trends for the monophthongization process of a diphthong (i.e., /ae/ > /ɛː/) was also found.

7. Discussion and conclusion

This study set out to provide acoustic evidence to support the sound changes reported to have occurred in colloquial Khmer in monosyllabic words with an obstruent + apical trill /r/ onsets. The trill /r/ was dropped in a relatively faster colloquial speech, and the following sound changes took place (a) the development of a distinct falling-rising pitch contour, (b) the aspiration of the initial obstruent and, (c) the raising and fronting at of low vowels causing low monophthongs to become diphthongs and in some cases diphthongs to become monophthongs. Acoustic analyses performed on 20 monosyllabic words of C_1(r)VV(C) structure produced both in reading and in colloquial pronunciations by two native speakers from Phnom Penh, the capital city of Cambodia, largely supported the above mentioned sound changes.

In this study, we also attempted to provide a plausible phonetic explanation for the changes that occurred. Our proposal was both perceptually and articulatorily (aerodynamically) based. We began with the assumption that colloquial pronunciation was more rapid than reading pronunciation and thus perhaps stronger coarticulatory effect. These coarticulatory effects then failed to be corrected by the Khmer listeners. To account for the development of the falling-rising pitch contour, we proposed that there is a greater drop in F_0 at word onset for vowels following a stop + [r] cluster onset than for vowels following a simple stop (e.g., a single stop) onset. This is due to the high volume of airflow needed for the production of the trill [r]. The high airflow conditions a high F_0 during the trill and creates a greater overall fall at word onset for CrV than CV words. Preliminary data to support this hypothesis has been obtained from Thai (Guion & Wayland 2003).

We suggested that the trill became devoiced in colloquial pronunciation due to the stringent aerodynamic requirement for voiced trills. At this point, the falling pitch contour could be perceptually reanalyzed and become associated with the following vowel. Then, perhaps, an increase in airflow volume after vowel onset was responsible for the observed rise in F_0 toward the end of the syllable resulting in the observed falling-rising pitch contour. This explanation is, however, tentative and awaits further experimental aerodynamic data. In turn, the voicelessness of the trill could be perceptually reanalyzed as aspiration associated with the initial obstruent.

It is important to note that this tonogenetic mechanism has not been previously reported in the literature. However, as Hombert (1977) stated, "in order to demonstrate that a sound change is phonetically motivated, one has to demonstrate first that these intrinsic perturbations are present in the speech signal and second, that their magnitudes are sufficient to be perceived (p.9)." Thus, perception experiments will be needed to ascertain that the reported drop in F_0 and oral airflow is sufficiently salient.

We also proposed that the perceptual reanalysis of the coarticulatory effect of the trill /r/ accounted for the diphthongization process of low vowels. As reported, the trill /r/ has the affect of raising the quality of low vowels at pronunciation. The high-onglide was reanalyzed as a non-low vowel causing the original low vowels to become diphthongized with the first element having a higher quality than the second (e.g., /a:/ > [ea]/ and /ɒ:/ > [ɔ^{a}]).

For aerodynamic reasons, the change from /a/, /a:/ to [ea] and /ɒ:/ > [ɔ^{a}] may also enhance the perceived degree of aspiration of the initial obstruents once the trill /r/ was lost in colloquial pronunciation. The relatively smaller oral cavity during the first part of the diphthongs may result in an increase in oral pressure and thus, a delay in obtaining a transglottal pressure drop suitable for voicing, thus a longer VOT for the preceding obstruents.

The coarticulatory effect of the trill [r] on the following vowels could also be extended to explain the monophthongization of non-low vowels (e.g., /ae/ > [ɛ:]). Specifically, the raising effect of the trill /r/ at onset of the following low vowels could result in an elimination of the low onglide in a diphthong that begins with a low onglide like /ae/ causing it to be heard as a monophthong.

In conclusion, this current study provided acoustic evidence as well as possible articulatory (aerodynamic) and perceptual based explanation for sound changes in Khmer, in particular the development of a falling-rising pitch contour conditioned by the loss of the alveolar trill. To our knowledge, this tonogenetic mechanism has not been reported in previous literature.

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Appendix A
Wordlist

1. /pram/	ប្រាំ	'five'
2. /praə/	ប្រើ	'to use'
3. /prap/	ប្រាប់	'to tell'
4. /pruəj/	ព្រួយ	'sad'
5. /priəj/	ព្រាយ	'spirit'
6. /proh/	ប្រុស់	'male'
7. /preᴵŋ/	ប្រេង	'oil, gas'
8. /preᴵŋ/	ព្រេង	'fortune'
9. /priəp/	ព្រាប	'pigeon'
10. /trɨw/	ត្រូវ	'correct'
11. /kru/	គ្រូ	'teacher'
12. /krɒː/	ក្រ	'poor'
13. /krŏən/	គ្រាន់	'enough'
14. /t̠ɕroʊt/	ច្រូត	'to harvest (rice)'
15. /t̠ɕrɨw/	ជ្រៅ	'deep'
16. /t̠ɕrŏəm/	ជ្រាំ	'muddy'
17. /srəj/	ស្រី	'female'
18. /srok/	ស្រុក	'district'
19. /sraː/	ស្រា	'alcohol'
20. /sraek/	ស្រែក	'shout'