

ON THE R>H SHIFT IN KIÊN GIANG KHMER

James Kirby
University of Edinburgh
j.kirby@ed.ac.uk

Đinh Lư Giang
Vietnam University of Social Sciences and Humanities
lugiangdinh@gmail.com

Abstract

This paper presents an acoustic and perceptual study of the r>h shift in the variety of Khmer spoken in Giồng Riềng district, Kiên Giang province, Vietnam. In Phnom Penh Khmer, /r/ is realized as [h] in syllable onsets and onset clusters, and accompanied by lowered pitch, breathiness, and in some cases a change in the quality of the following vowel. In Kiên Giang Khmer, the r>h shift is accompanied by pitch lowering, but without changes in aspiration or vowel quality, and spectral measures did not indicate substantial differences in voice quality. Consistent with their productions, users of this dialect appear to rely solely on differences in pitch to identify these lexical items. We discuss the implications of our findings for Khmer dialectology, mechanisms of sound change, and variation in the realization of rhotics more generally.

Keywords: Khmer, rhotics, sound change, tone

ISO 639-3 codes: khm

1 Introduction

Standard (Central) Khmer, the national language of Cambodia, contains a phoneme /r/ which is realized phonetically as an alveolar trill [r] in words such as ក្រុ /kru:/ ‘teacher’ or រៀន /rien/ ‘to study’. This realization of /r/, which is taught in schools and promulgated through radio and television, is a highly salient feature of the prestige dialect.¹ In the colloquial speech of the capital Phnom Penh (hereafter PP), however, /r/ in onsets and onset clusters is realized as a glottal fricative [h], and accompanied by a falling or falling-rising pitch contour and changes to the quality of the following vowel (Noss 1966; Huffman 1967; Sakamoto 1968; Wayland and Guion 2005; Filippi 2006; Kirby 2014; Filippi and Heap 2016). In this article, we will refer to this phenomenon as the *r>h shift* (Pisitpanporn 1994).

While several phonetic studies have now addressed the acoustic and perceptual basis of this alternation in PP Khmer (Wayland and Guion 2005; Kirby 2014a), the occurrence of r>h is not limited to the dialect of Cambodia’s capital. The r>h shift has also been described as a characteristic of the varieties of Khmer spoken in parts of historical Cochinchina, the Mekong Delta region of present-day Vietnam (Thạch 1999; Nguyễn 2010; Đinh 2011, 2015). However, no acoustic studies of these varieties have yet been conducted.

This paper presents an acoustic and perceptual study of the r>h shift in the variety of Khmer spoken in Kiên Giang province, Vietnam (hereafter KG). We elected to investigate KG Khmer because, while previous work (Thạch 1999) describes an incipient pitch contrast in this dialect, no mention is made of the other acoustic features known to accompany this variable in PP Khmer. We discuss the implications of our

¹ See Filippi (2006) for a historical overview of the development of Standard Khmer, with particular attention to the role of the orthography.

² Most phonological inventories of Khmer, beginning at least with Henderson (1952), do not include phonemic aspirated stops, and instead treat aspirated onsets as clusters of C + /h/. The primary evidence cited for this analysis is the result of applying the nominalizing infix -am(n)- to a base such as ខេង /khəŋ/ ‘angry’, which yields forms like កំបុង [kamhəŋ] ‘anger’. A similar argument is advanced for related languages, such as Old Mon (Jenny and

findings for Khmer dialectology, our understanding of the phonetics of the r>h shift, and the phonetic mechanisms underpinning rhotic sound change more generally.

2 Background

2.1 History of Khmer in southern Vietnam

The Mekong Delta region of present-day Vietnam has been inhabited since pre-Angkorian times, possibly as early as the 4th century BCE (Hà 1986; Stark 1998). Although the precise date when the Khmers arrived in the southern peninsula has not been determined, archeological and linguistic evidence suggests (Old) Khmer may have been spoken in the region from at least the 7th century CE, and possibly much earlier (Stark 1998; Vickery 2003). Most scholars seem to agree that Vietnamese speakers were increasingly present in the region from the early 1600s (Phoeun 1995; Vickery 2011), and speakers of Bahnaric, Austronesian, and Chinese languages have also inhabited the area for some centuries (Ferlus 1989). The 2009 census reports 1,260,640 ethnic Khmer in Vietnam, the vast majority of those in the Mekong Delta (General Statistics Office of Vietnam 2010). Of these, roughly 5% are Khmer monolinguals (mostly older speakers and those living in extreme frontier areas) and another 15% are mostly Vietnamese monolinguals (mostly younger people of mixed Khmer-Vietnamese heritage and/or living in urban areas; see Dinh 2011).

Khmer dialects are often divided into three groups: Central or ‘standard’, Western (Cardmom/Chanthaburi) and Northern (Surin) varieties (Ferlus 1992; Sidwell 2009; Lewis et al. 2015). While the Dângrêk and Krâvanh mountain ranges form a natural barrier separating Northern and Western Khmer from the varieties spoken in the central plain, no such natural barrier exists between the central plains and the Mekong Delta. As a result, the Southern Khmer or *Khmer Krom* (literally ‘Khmer from below’) dialects, which are generally mutually intelligible with varieties spoken in central Cambodia, are subsumed as part of the Central Khmer construct. Despite this, considerable lexical and phonological differences are said to exist (Martini 1946; Taylor 2013:274, note 2; Pain 2014). To the best of our knowledge, no comprehensive survey of the Khmer dialects of Vietnam has yet been attempted.

Figure 1: Map of southern Cambodia and Vietnam, highlighting Giồng Riềng district (yellow) in Kiên Giang province (red).



2.2 Kiên Giang Khmer

Kiên Giang, one of Vietnam's southernmost provinces, shares its northwestern border with Kampot province in Cambodia (Figure 1). In Khmer it is sometimes referred to by the toponyms ក្រោមុនស /kramuən sa:/ or ណាត /riecie/. The provincial capital, Rạch Giá, is located some 250 km from Hồ Chí Minh City. While by no means the most heavily populated Khmer region of the country, Kiên Giang is home to some 210,899 Khmers, or roughly 10% of the provincial population (General Statistics Office of Vietnam 2010).

Our study was conducted in the district of Giồng Riềng, located about 50 km east-southeast of Rạch Giá. According to the 2009 census, the population of Giồng Riềng was 212,716, of which 177,008 were ethnic Kinh (Vietnamese) and 33,982 ethnic Khmer, or about 15% of the total population. In the hamlet of Ngọc Chúc, home to most of the participants in our study, around one third of the population is Khmer: out of a total population of 12,323, the census lists 8,259 Kinh, 3,980 Khmer, 74 Hoa (Chinese) and 10 ‘other’.

While Vietnamese is the official language of education and government, our impression is that oral usage of Khmer language among the Khmers of Giồng Riềng is robust. Several of our police and government liaisons were themselves Khmer, and while also fluent in Vietnamese spoke Khmer at home with their spouses and children. Although to our knowledge no sociolinguistic or ethnolinguistic studies have been conducted in Kiên Giang province, fieldworkers report that oral (if not written) use of Khmer in other southern provinces, such as Sóc Trăng and Trà Vinh, is similarly vigorous (Nguyễn 2010; Đinh 2011, 2015). However, there is anecdotal evidence to suggest that the rate of Vietnamese-language dominance is on the rise among younger Khmers in the Delta (Taylor 2013).

2.3 Previous studies of the r>h shift

2.3.1 In Cambodian dialects

The r>h shift in the colloquial Phnom Penh dialect has been noted since at least the 1960s (Noss 1966; Huffman 1967; Sakamoto 1968; Mai 1988; Pisitpanporn 1994). Pisitpanporn (1994) suggests this pronunciation dates to the late 19th century, if not earlier. Precise descriptions vary, but most authors describe some combination of (i) a lowered or dipping pitch (f0) movement; (ii) diphthongization of low vowels (so /aa/ > [ea], /aa/ > [əa]); and (iii) aspiration, with /r/ > [h] in absolute initial position (e.g. ឃីស /rien/ > [hiən] ‘to study’) and possibly producing the percept of an aspirated stop if part of a cluster (e.g. ឃា /tra:/ > [tʰea] ‘seal, stamp’).^{2,3} Filippi and Heap (2016) describe such variants as phonetically complex realizations involving breathy voice, pitch variation, diphthongization, and a greater degree of closure (Filippi and Heap 2016, xxxii), but transcribe only voice and vowel quality differences.

To the best of our knowledge, the first acoustic investigation of the r>h shift in PP Khmer was conducted by Wayland and Guion (2005), who studied the speech of two speakers. They showed that the loss of /r/ was accompanied by aspiration, a falling-rising pitch contour, and a change in vowel quality. Building on Wayland and Guion’s work, Kirby (2014a) found that, in addition to the acoustic correlates previously mentioned, the spectral balance measures H1*-H2* and H1*-A3* served to distinguish colloquial PP Khmer pronunciations of forms like ឃា /kra:/ from forms like ឃ /ka:/. Kirby also showed that in colloquial pronunciations such as [kʰəa] and [tʰea], the aspiration on the initial consonant is roughly 50% of the duration of a ‘true’ aspirated consonant (i.e., a phonological /Ch/ cluster). In a pair of perceptual studies, Kirby further demonstrated that f0, aspiration and voice quality, but not vowel height, all contribute to the perception of the contrast.

Mention of the r>h shift has also been made for other Cambodian Khmer dialects. Huffman (1967) describes this characteristic PP feature as having spread to Kampong Cham and parts of Kandal province. Minegishi (1986) describes the r>h shift in the Takeo dialect. Pisitpanporn (1999) notes that this

² Most phonological inventories of Khmer, beginning at least with Henderson (1952), do not include phonemic aspirated stops, and instead treat aspirated onsets as clusters of C + /h/. The primary evidence cited for this analysis is the result of applying the nominalizing infix -am(n)- to a base such as ខេង /khəŋ/ ‘angry’, which yields forms like កំហេង [kamhəŋ] ‘anger’. A similar argument is advanced for related languages, such as Old Mon (Jenny and McCormick 2015). We will follow this tradition here, but transcribe phonetically aspirated stops as such, e.g. [kʰəŋ].

³ Mai (1988) describes the pitch movement accompanying the r>h shift as being similar to the Vietnamese dipping tone *hỏi*, and the initial consonant in /Cr/ onset clusters as aspirated (*bật hỏi*) when the /r/ is lost. This is reflected in her transliterations, e.g. *prám* (Khmer ឃា ‘five’) is transliterated as «phém», *trâu* (ឃី ‘correct’) as «thâu», etc.

pronunciation can be heard in Takeo, Kampong Cham, Kampong Chhnang, Kampong Thom and Kratie provinces in Cambodia, although not always with an accompanying drop in pitch, citing forms from Kampong Cham and Kratie such as ឃោន /kṛe:/ > [k^hɛ:] ‘bed’.⁴

2.3.2 In Khmer Krom (Vietnamese) dialects

While the Northern Khmer dialects spoken in Thailand have been the subject of considerable linguistic study (Premsrirat 1997), there has been less work on the Khmer dialects of Vietnam. One of the few studies to date is Thạch (1999), who focused on the process of monosyllabification in Kiên Giang Khmer. This paper contains a considerable number of pairs in which contrast is maintained by falling pitch only, e.g. /hiən/ ‘dare’ vs. /riən/ > [hiən] ‘study, learn’, /ka:/ ‘neck’ vs. /kra:/ > [kà:] ‘poor’ (1999:93). Thạch states that, while low pitch accompanies loss of /r/ in both syllable onsets and onset clusters, /r/ is manifested as a glottal fricative [h] in absolute initial position only (1999:87). Furthermore, he does not describe any vowel quality changes or differences in voice quality.

An r>h shift (with an accompanying fall in pitch) has also been noted in work on the Khmer dialects of Sóc Trăng, Trà Vinh, and An Giang provinces (Nguyễn 2008, 2010; Đinh 2015). However, these studies have focused primarily on language attitudes, vitality, and bilingualism, and to the best of our knowledge no phonetic data on the r>h shift has previously been gathered or analyzed from these dialects.

3 Acoustic study

The goal of the acoustic study was to collect recordings of spoken Kiên Giang Khmer in order to acoustically analyze the r>h shift. In particular, we were interested in corroborating the transcriptions of Thạch (1999) in order to compare them to acoustic studies of the r>h shift in PP Khmer.

3.1 Methods and materials

3.1.1 Speakers

20 native Khmer Krom speakers (7 female) were recruited from the community in and around Ngoc Chuc hamlet, Giồng Riềng district, Kiên Giang province. All participants were born and raised in Kiên Giang province, either in Ngoc Chuc or in nearby villages or communes. Participants ranged in age from 19 to 61 years (mean = 38) and had varying degrees of education: 5 had completed high school, 9 had completed 5-9 years of schooling, and 6 had no more than a 3rd grade education.

All of our participants were to some degree proficient in the local variety of Southern Vietnamese. Participants were asked to describe the degree to which they used Khmer (as opposed to Vietnamese) in their daily lives on a percentage scale. Responses ranged from 20% to 90%, with all but one participant reporting using Khmer 50% or more of the time. There is some evidence for a moderate negative correlation between education and age in our sample (Pearson’s $r=-0.4$), but self-reported Vietnamese proficiency was not a significant factor in any of our statistical analyses. No participants reported any history of speech or hearing difficulties. Participants were compensated with a small fee.

3.1.2 Stimuli

In designing the word list for acoustic recording, we first attempted to use the word list from the study of Kirby (2014a) on PP Khmer. However, in speaking with members of the community, it became apparent that they were unfamiliar with several of the words used in the earlier study, while others had different meanings in the local dialect. In the end, we settled on 19 items (see Appendix) to record for acoustic analysis. Because no bilabial- or palatal-initial minimal triplets could be identified, our wordlist contains only coronal- and velar-initial stop items.

⁴ A reviewer notes that [k^haɛ] is also a possible pronunciation in Kratie and some districts of Kompong Cham, such as Han Chey district.

3.1.3 Procedure

Because nearly all our participants were illiterate in Khmer, and because Khmer orthography indicates /r/ and thus introduces a bias towards the literary register, participants were prompted orally with the Vietnamese equivalent of the target item and asked to produce the appropriate equivalent in KG Khmer. Speakers were recorded producing each item three times in the phrase ខ្សោយ ____ ទេ /knom tha: ____ tiət/ ‘I say ____ again’. In order to elicit colloquial forms, participants were encouraged to use ‘mild voice’ (*giọng nhẹ* or *tiếng nhẹ*) or to use the ‘local speech’ (*giọng địa phương*), but as most participants only controlled one register, this may have been unnecessary. 24 bit, 44.1 kHz recordings were captured using a Marantz PMD-661 portable solid-state recorder and a Beyerdynamic Opus 55.18 Mk II omnidirectional headset condenser microphone fitted with a CV 18 preamplifier. Recordings were made in reasonably quiet rooms at the Cái Đuốc Giữa temple located in Ngọc Bình temple village, Ngọc Chúc hamlet, Giồng Riềng district, Kiên Giang province.

3.1.4 Processing and analysis

Recordings were transferred to PC and the target items segmented using Praat 5.2.26 (Boersma and Weenink 2011). Due to variation between participants and some recording errors, not all items were recorded for all participants; for further details, see the supplementary materials (Kirby and Đinh 2017a,b).

Voicing onset was defined as the point of first ascending zero-crossing preceding the first periodic wave component of the acoustic waveform. For stops, Voice Onset Time (VOT) was then measured as the duration from the stop burst to voicing onset; for fricatives, we measured the duration from the onset of friction noise to onset of voicing.

Spectral measures taken from the nuclear vowel at 11 equally spaced timepoints, as a way to normalize for overall vowel duration. We estimated f0 using a 15 ms frame duration, a pitch floor of 40 Hz, and a pitch ceiling of 600 Hz. Formants extraction proceeded by computing LPC coefficients using Praat’s implementation of the Burg algorithm, using a 25 ms analysis window with pre-emphasis applied from 50 Hz, and then smoothed using the `Track...` function. Harmonic structure was estimated from long-term average spectra calculated over 25 ms windows centered at each measurement point.

For those timepoints where f0 could be accurately determined, amplitudes of the first two harmonics (H1 and H2) were measured along with the amplitude of the most prominent harmonics of the first three formants (A1, A2, A3). For H1, this was done by finding the harmonic with the greatest amplitude in the frequency range $f_0 \pm (f_0/10)$; for H2, we searched in the range $2f_0 \pm 2(f_0/10)$; and for A1, A2, and A3, we searched the range $F_n \pm (F_n/10)$. All measures were then corrected for the effects of F1 and F2 frequencies and bandwidths on the vocal tract transfer function. For A3, we additionally corrected for the effects of F3; see Iseli et al. (2007) for details.

The corrected measures were used to compute H1*-H2* (an acoustic correlate of open quotient) along with H1*-A1*, H1*-A2*, and H1*-A3* (correlates of spectral tilt). We also measured the cepstral peak prominence (CPP; Hillenbrand et al. 1994), a measure of how far the cepstral peak emerges from the cepstrum background. CPP has been used successfully to distinguish breathy from modal vowels in a number of languages (see e.g. Blankenship 2002). For the spectral measures, higher values are expected for breathy as opposed to modal voiced segments, due to enhanced H1 amplitude and attenuation of higher frequencies (Hillenbrand et al. 1994; Gordon and Ladefoged 2001), while a more prominent cepstral peak is expected for normally phonated speech, which will generally have a more well-defined harmonic structure than breathy speech.

Prior to conducting spectral analyses, we removed individual measurements where there were obvious formant tracking and amplitude estimation errors; see Kirby and Đinh (2017b) for details. We also removed two items with word-final obstruents, សក /sak/ ‘hair’ and ស្រក /srak/, /sraŋ/ ‘to drip’, due to the fact that they were frequently accompanied by strong final glottalization.

3.2 Results

Data were analysed using linear mixed-effect regressions as implemented in the R package `lme4` (Bates et al. 2014). Post-hoc tests were conducted using the `lsmeans` package (Lenth 2016).

3.2.1 Voice Onset Time

Figure 2 shows Voice Onset Time (VOT) averaged over speakers, items and repetitions by place of articulation. While aspirated stops have longer VOT than unaspirated stops, there is no difference between the VOT of the onset in forms like /ku:/ > [ku:] ឃ ‘pair’ and /kru:/ > [kǔ:] ឃូ ‘teacher’, both realized with initial voiceless unaspirated [k] in KG Khmer. Pairwise comparisons based on a mixed-effects regression are given in Table 1.

Figure 2: VOT for coronal (left) and dorsal (right) stop onsets. Labels /tr/ > [t] and /kr/ > [k] indicate Standard Khmer clusters that are realized as singleton stops in Kiên Giang Khmer.

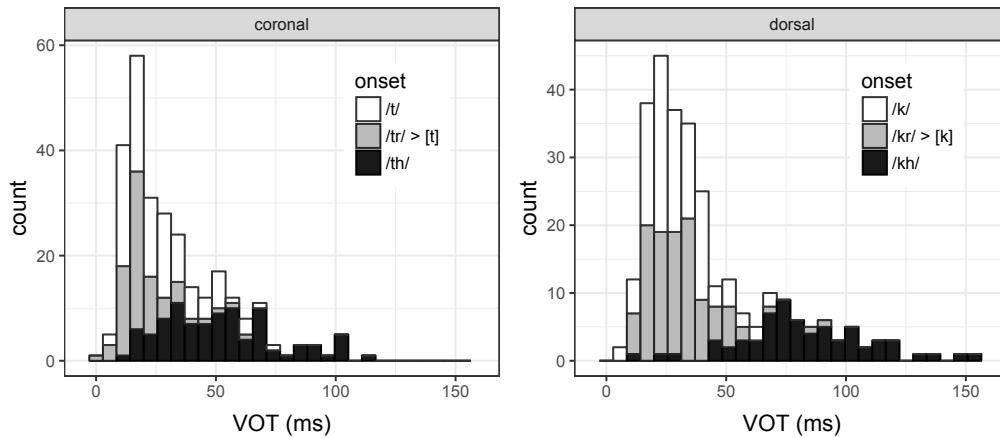


Table 1: Results of within-place, post-hoc pairwise comparisons for KG stops, based on a linear mixed-effects model with TYPE (plain stop, aspirated stop, or ‘underlying’ stop + /r/ cluster), PLACE OF ARTICULATION (coronal or dorsal) and their interaction as fixed effects, along with subject-specific intercepts and crossed random slopes for all fixed terms and a random intercept for item. Fractional degrees of freedom are approximated using the Satterthwaite method, as implemented in the `lmerTest` package (Kuznetsova et al. 2016). P values are adjusted for multiple comparisons based on the Tukey method for a family of 3 means.

contrast	estimate	SE	df	t ratio	p-value
/t/:/th/	-23.79	5.05	20.24	-4.71	<.001
/t/:/tr/ > [t]	7.98	3.86	13.34	2.07	0.13
/th/:/tr/ > [t]	31.78	4.95	19.42	6.42	<.0001
/k/:/kh/	-51.93	6.76	23.08	-7.69	<.0001
/k/:/kr/ > [k]	-0.43	3.34	8.73	-0.13	0.99
/kh/:/kr/ > [k]	51.49	6.47	22.43	7.96	<.0001

3.2.2 Fricative noise duration, amplitude, and spectral moments

Figure 3 plots histograms of the noise duration for the fricatives /h/ and /s/. Similar to the stops, noise duration fails to distinguish the onsets in pairs like ឃ៊ស /rien/ > [hiɛi] ‘to study’ and ឃុនស /hien/ ‘to dare’, both produced with an initial glottal fricative [h] in KG Khmer. Post-hoc pairwise comparisons based on a mixed-effect linear regression (not shown here) were not significant for either place of articulation.

In addition to noise duration, we compared the overall noise amplitude as well as the first two spectral moments of the frication periods of the alveolar and glottal fricatives (Behrens and Blumstein 1988; Jongman et al. 2000). To obtain the spectral measures, we first applied pre-emphasis (6 dB from 80 Hz) to the fricative portions of smoothed FFT power spectra computed with a 20 ms Gaussian window. The center of gravity was then computed by finding the average frequency over the entire frequency domain, weighted by the power spectrum. Summary statistics for noise amplitude and first two spectral moments are given in Table 2. Within-place post-hoc tests revealed no significant differences between the fricative types for any of these measures.

Figure 3: Noise duration for coronal (left) and glottal (right) fricative onsets. Labels /sr/ > [s] and /r/ > [h] indicate the Kiên Giang realizations of Standard Khmer onsets /sr/ and /r/, respectively.

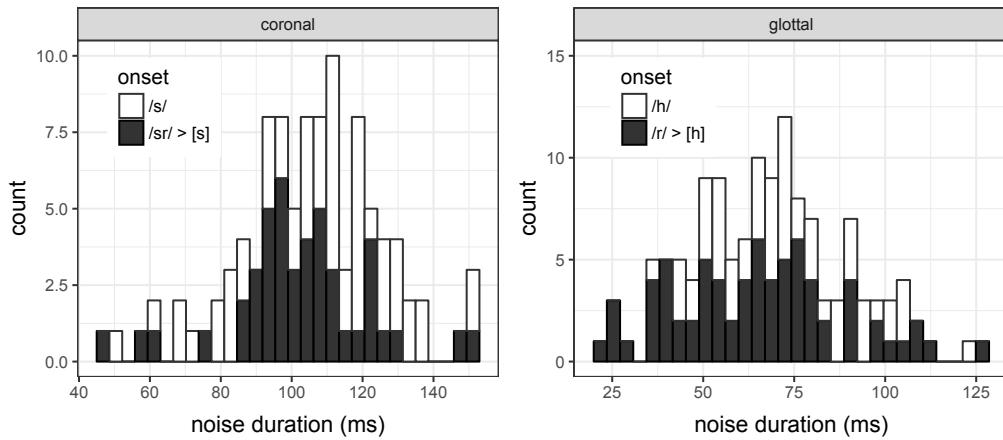
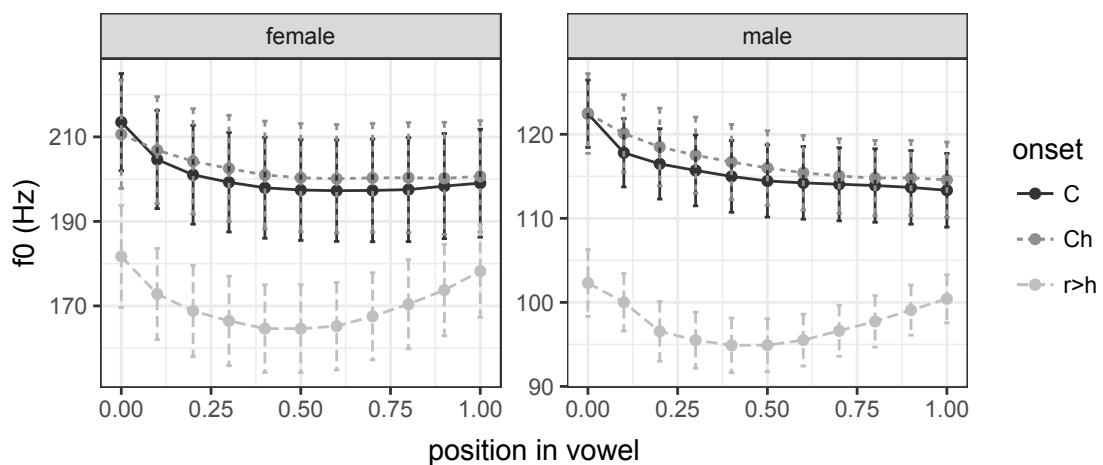


Table 2: Means (standard deviations) for noise amplitude (in dB) and first two spectral moments (in Hz/MHz) for /s/, /h/, /sr/, and /r/, averaged across speakers, items, and repetitions.

onset	Amplitude (dB)	Spectral mean (Hz)	Variance (MHz)
/s/	52 (4)	8179	1439
/sr/ > [s]	52 (4)	8108	16.7
/h/	57 (7)	4449	7.4
/r/ > [h]	58 (7)	5162	6.6

Figure 4: f_0 (in Hz) by gender and onset type, averaged over subjects, items, and repetitions. Vowels following unaspirated onsets /t k/ are in solid black (C), those following aspirated onsets /th kh s h/ are in dark gray (Ch), and those following onsets with /r/ in Standard Khmer /tr kr sr r/, realized as [h] and/or with a falling-rising tone in KG Khmer ($r>h$), are in light gray. Error bars indicate standard error of the mean at each timepoint.



3.2.3 Fundamental frequency contour (f0)

Figure 4 shows the f0 contours in the vowels following words like ពី /ku:/ ‘pair’ (labeled C), ឃិ /thu:/ ‘fluid’ (labeled Ch), and ក្រុ /kru:/ > [kū:] ‘teacher’ (labeled r>h). Items which have /r/ in Standard Khmer show a clear falling-rising f0 contour that is ~15-25 Hz lower than the average f0 for other voiceless segments. As any effect of aspiration on f0 appears to be negligible at best, we treat all items which would not contain an /r/ in Standard Khmer as a single class, labeled *plain*, from this point forward.

While there are obvious within-gender differences between onset types, we may also ask if there are between-gender differences within onset type, as expressed by differences in the average slope of the f0 contour. Statistically, one way to test for such differences is to fit a model to our data using random slopes for each subject while allowing for a different average slope for each gender. Between-gender comparisons of the difference between the average slopes for each onset type are not significant for either plain or r>h onsets, suggesting no difference between genders.

3.2.4 Vowel quality

Many previous researchers (Noss 1966; Pisitpanporn 1994; Pisitpanporn 1999; Wayland and Guion 2005; Wayland and Guion 2007; Kirby 2014a) have reported a vowel quality change in PP Khmer, whereby low monophthongs diphthongize following /t/, e.g. ពន្ល /kra/ ‘poor’ > [k^hōa], ពន្ល /tra:/ ‘seal, stamp’ > [t^hea].⁵ However, Thäch (1999) does not describe such a change, and as seen in Figure 5, we do not observe one in our data either. The almost total overlap between the formant trajectories for vowels following ‘plain’ onsets (e.g. /k/ > [k]) and those following simplified clusters (e.g. /kr/ > [k]) suggests that onset type does not correlate with a difference in vowel quality. Post-hoc pairwise comparisons (see supplementary materials) similarly fail to show evidence of any statistically significant differences due to onset type.

The exception is the diphthong /ie/, which is significantly raised in the r>h context (mean F1 around 440 Hz) compared to in the plain context (mean F1 around 645 Hz). Pisitpanporn (1999) describes a similar monophthongization of diphthongs in PP Khmer, e.g. ីរុះ /srae/ > [sě:] ‘paddy field’; acoustic evidence for this change in PP Khmer was found by Wayland and Guion (2005) but was not observed by (Kirby 2014a). One possible explanation for this effect is that the articulatory nature of the r>h shift differs for absolute-initial /r/ compared to /r/ in clusters; however, this leaves unexplained the lack of such a difference for the pair ីនិ /hiŋ/ ‘altar’ and ីនិ /riŋ/ > [hiŋ] ‘hard’. As the diphthong /ie/ only occurs in two forms in our corpus, ីនិ /hien/ ‘to dare’ and ីនិ /rien/ > [hiēn] ‘to study, learn’, it is also possible that the difference reflects a lexically specific pronunciation. Additional data would be necessary to do more than speculate, so we leave this issue open (but see section 3.2.5 on voice quality).

3.2.5 Voice quality

Previous impressionistic as well as acoustic studies of PP Khmer have described a breathy voice quality accompanying the r>h shift. As noted in 3.1.4, acoustically this difference is expected to manifest in larger differences in spectral magnitude for breathy as opposed to modal voiced segments. In PP Khmer, Kirby (2014a) found that, at least at vowel onset, H1*-H2* and H1*-A3* were around 5-8 dB greater for r>h items compared to unaspirated stop onsets. In KG Khmer, however, these spectral balance measures showed much smaller differences, and usually not in the direction than would be expected if the r>h forms were characterized by breathier voicing.

⁵ Leang (2011) describes a vowel quality change in some, but not all, lexical items which undergo an r>h shift in the Khmer spoken in Lvea Aem district, Kandal province.

Figure 5: Formant trajectories (F_1/F_2) averaged over subjects, items and repetitions. Formants of vowels following plain onsets /t th k kh s h/ are in solid black, those following onsets with /r/ in Standard Khmer /tr kr sr r/ are in dashed gray. Error bars show one standard deviation from the mean at each timepoint.

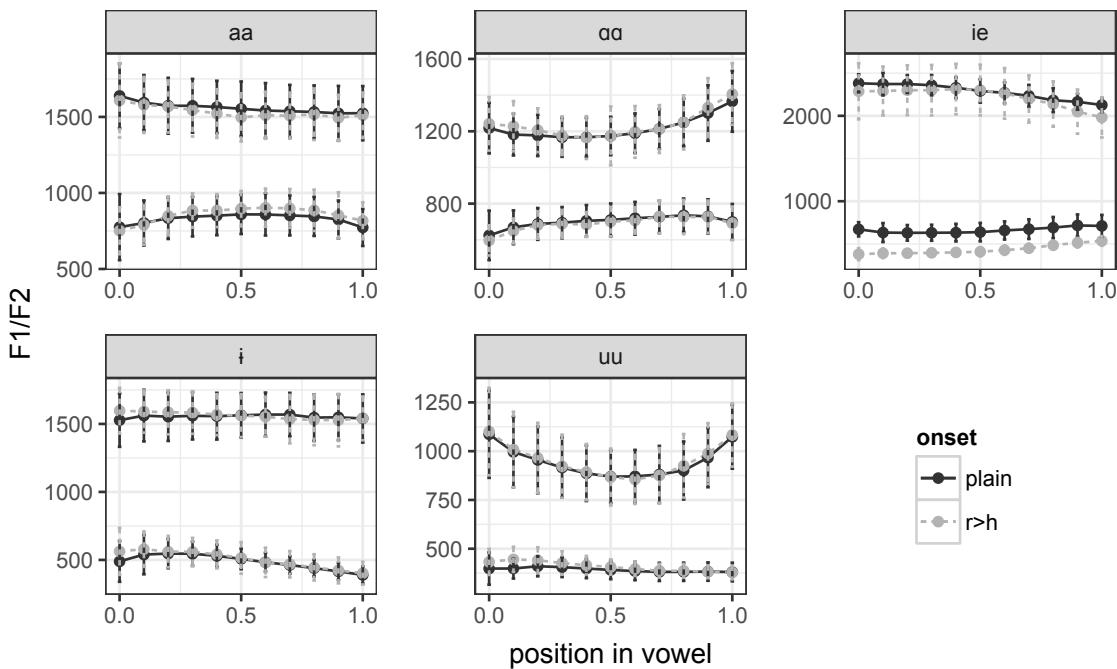


Figure 6 shows the amplitude trajectories for three of the measures we examined: H1*-H2*, H1*-A3*, and cepstral peak prominence (CPP); corresponding statistical estimates are given in Table 3.⁶ For H1*-H2*, mean differences between onset types were significant, but on the order of 1–3 dB. For H1*-A3*, differences were significant only for the diphthong /ie/: the difference in spectral magnitude was much greater for /hien/ ឃែន ‘dare’ than for /rien/ > [hien] ឃែន ‘to study’. It is not clear why this difference should obtain between this particular pair of words, or why the difference should be so prominent for this measure (as well as for H1*-A2*). Given that we obtained recordings of /hien/ from just 5 speakers, it is possible that this reflects individual differences; it is also possible that there are systematic differences in how ‘true’ and ‘derived’ /h/ are articulated in absolute-initial position (although no such difference is observed between /riŋ/ > [hɪŋ] ឃុង ‘hard’ and /hiŋ/ ឃីង ‘altar’). In any case, this issue deserves further study.

For CPP, mean differences are again on the order of a few dB, but here the effect is in expected direction, with lower peak prominence for r>h forms compared to plain onsets. Exactly how large of a difference in magnitude we should expect here is not clear. For example, Esposito and Khan (2012) found average CPP differences between modal and breathy vowels in White Hmong to be on the order to 10 dB, while Blankenship (2002) found differences of just a few dB for Mazatec, and small positive differences (breathy > modal) for Chong. Given that these and other studies have found significant variability in the acoustic measures which reliably distinguish breathy from modal voicing in the world’s languages, we cannot say with certainty that there are no voice quality differences between words with plain and r>h onsets in KG Khmer, but only that any such differences differ in magnitude, and probably sign, from those in PP Khmer.

⁶ Results were similar for H1*-A1* and H1*-A2*; see supplementary materials.

Figure 6: Amplitude trajectories of H1*-H2*, H1*-A3*, and CPP for vowels in KG Khmer, averaged over subjects, items and repetitions. Vowels following plain onsets /t th k kh s h/ are in solid black, those following onsets with /r/ in Standard Khmer /tr kr sr r/ are in dashed gray. Error bars show one standard deviation from the mean at each timepoint.

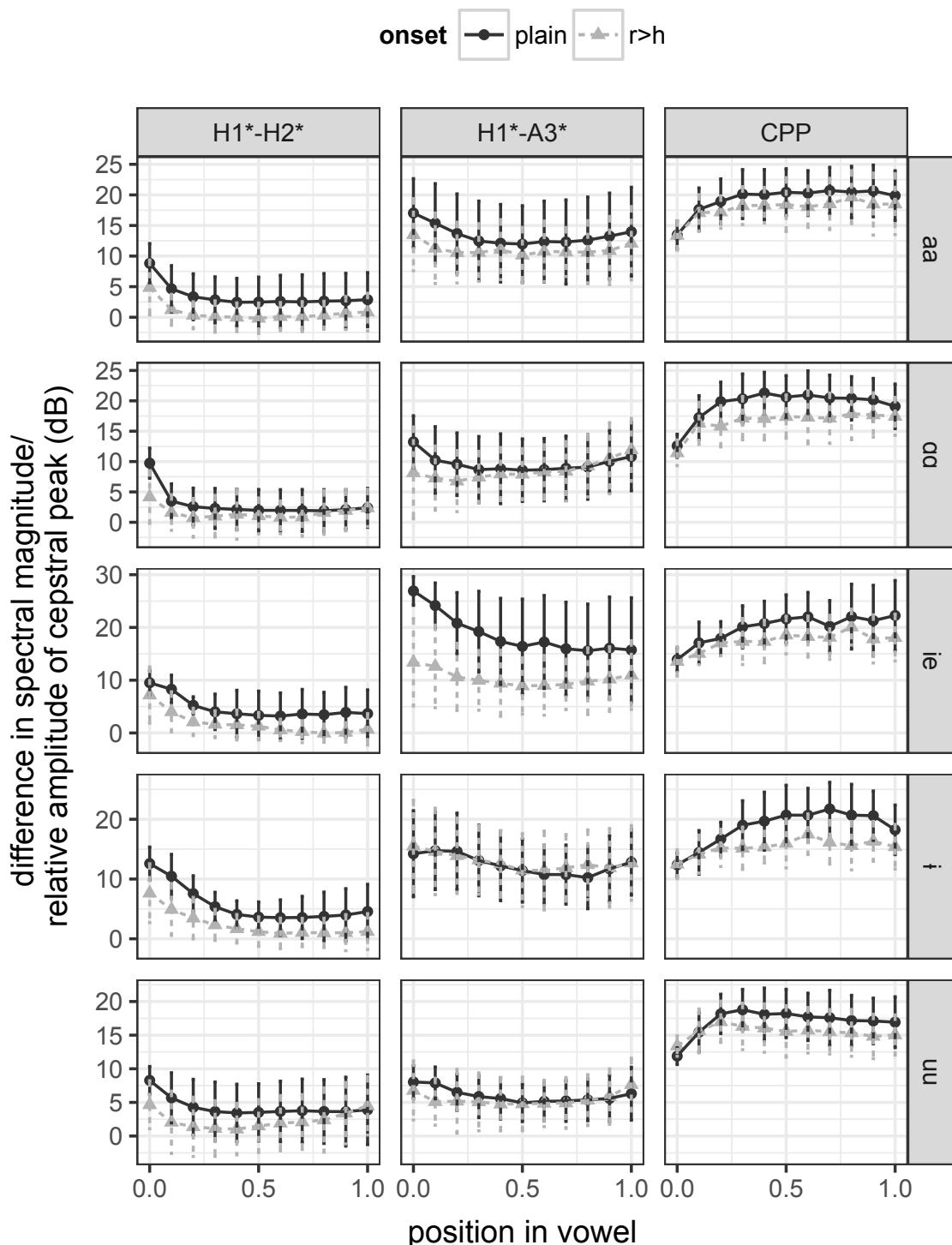


Table 3: Post-hoc comparisons for three voice quality measures based on linear mixed-effects models with centered POSITION IN VOWEL, ONSET TYPE (plain or r>h), VOWEL (5 levels) and an ONSET TYPE:VOWEL interaction as fixed effects, along with subject-specific intercepts and random slopes for ONSET TYPE and VOWEL and a random intercept for item. The diff column shows the mean estimated difference (in dB) between plain and r>h onsets for a given vowel; difference is always plain minus r>h. Fractional degrees of freedom are approximated using the Satterthwaite method, as implemented in the lmerTest package (Kuznetsova et al. 2016).

vowel	diff	SE	df	t ratio	p-value
H1*-H2*					
/a:/	2.63	0.72	27.90	3.63	0.001
/ɑ:/	1.26	0.89	21.69	1.42	0.17
/ie/	1.88	1.05	24.28	1.79	0.09
/i/	3.62	1.01	20.56	3.60	0.002
/u:/	2.61	0.72	26.75	3.64	0.001

vowel	diff	SE	df	t ratio	p-value
H1*-A3*					
/a:/	1.11	0.69	26.50	1.61	0.12
/ɑ:/	0.64	0.83	19.31	0.78	0.45
/ie/	4.00	1.03	25.89	3.9	<0.001
/i/	-0.67	0.95	25.89	-0.7	0.49
/u:/	0.71	0.67	24.16	1.06	0.30

vowel	diff	SE	df	t ratio	p-value
CPP					
/a:/	1.95	0.67	26.81	2.93	0.007
/ɑ:/	2.80	0.81	19.61	3.46	0.003
/ie/	2.38	0.99	25.91	2.38	0.025
/i/	3.84	0.93	19.44	4.15	<0.001
/u:/	1.75	0.65	24.40	2.69	0.013

4 Perception study

The second component of the current study sought to determine the acoustic cue(s) used by KG Khmer listeners to distinguish forms like ក្រ /kru:/ from those like គុ /ku:/. As the acoustic study found little or no vowel quality differences between forms affected by the r>h shift and those that were not, we conducted a single two-alternative forced choice perceptual task by creating a continuum between [ku:] and [kǔ:] as described below.

4.1 Methods and materials

4.1.1 Participants

All participants in the acoustic production study also participated in the perception experiment.

4.1.2 Stimuli

To create the perceptual stimuli, a 500 ms token of [ku:] was synthesized with f0 of 150 Hz at vowel onset and 140 Hz at vowel offset, using the KlattGrid synthesizer implemented in Praat. This token was then used as a basis for creating three experimental conditions. First, a seven-step f0 continuum was generated by

decreasing f0 at vowel midpoint in 10 Hz (0.95 erb) steps, with the lowest dip to 90 Hz. This continuum was then used as the basis for two additional continua: one in which aspiration was increased uniformly by 70 ms in all seven items, yielding a continuum of [k^hu:] ~ [k^hū:], and one in which breathy voice quality was simulated by increasing breathiness amplitude (ATU) and spectral tilt (TL) to 75 and 24 dB, respectively, yielding a continuum of [k^bu:] ~ [k^bū:]. For more details, including KlattGrid specifications, see Kirby (2014a).

4.1.3 Procedure

Stimulus presentation and data collection were performed using Praat 5.2.26 (Boersma and Weenink 2011). Subjects were presented with auditory stimuli via headphones at a comfortable listening level. In each trial, participants responded via keyboard to indicate which of two lexical items, ឯ /ku:/ ‘pair’ or ឬ /kru:/ ‘teacher’, they thought the stimulus most closely resembled. Pictures corresponding to the lexical items were displayed on the laptop screen; at no point were participants exposed to orthographic representations, Khmer or otherwise. Participants first completed a short training session where they were presented with unambiguous stimuli from the continuum endpoints; all were able to correctly identify at least 80% of the category exemplars before proceeding to the main test.

The 21 stimuli were presented in 10 randomized blocks for a total of 210 trials. Each item was presented only once per trial; participants could take as long as they needed to respond, but could not hear the item repeated. The experiment took approximately 10-15 minutes to complete.

4.2 Results

Responses were modeled using a generalized linear mixed effects model (GLMM) with a logistic link function (see Kirby 2014a, Appendix B). Both CONDITION (f0 manipulation only; f0 with increased aspiration; or f0 with simulated breathy voicing) and (centered) STIMULUS STEP (point on f0 continuum), along with their interaction, were entered as fixed terms; we also included a random intercept for each subject and subject-specific slopes for STIMULUS STEP (models including random slopes for CONDITION failed to converge).

Initial inspection of the individual response patterns suggested that some participants may have been responding at random, or in any event were not performing better than chance. We therefore repeated the analysis, excluding the response data from those 7 participants for whom a one-unit change in STIMULUS STEP failed to increase the probability of a /kru:/ response by at least 5%. These results are reported below; inclusion of these 7 participants does not substantively alter our findings, although the coefficient estimate for STIMULUS STEP decreases.⁷

As seen in the left panel of Figure 7, the only significant effect is that of STIMULUS STEP: a one-step increase in medial f0 dip maximally increased the probability of a /kru:/ response by about 24% (step 3 to step 4), but neither addition of aspiration nor of breathy voice had a significant effect (Table 4). The results of the same experiment conducted with PP listeners in Kirby (2014a) is provided in the right panel of Figure 7 for comparison. Note that the f0 drop between stimulus steps 3 and 4 appears to be the 50% crossover point for both groups, but for PP listeners this was the case only when aspiration was increased to 70 ms. This suggests that the contrast in PP is signalled by a complex of acoustic cues, while in KG, it is a purely f0-based contrast.

⁷ We also re-examined the production results in Section 3 for differences between these 7 subjects and the remaining 13, but did not find any evidence of systematic differences in the production of pitch height, vowel quality, or voice quality. Further details and statistical tests can be found in the supplementary materials (Kirby and Đinh 2017b).

Figure 7: Left: average probability of /kru:/ responses in the KG perceptual experiment (with some participants excluded; see text). Right: comparison from same experiment conducted with PP listeners from Kirby (2014a). Conditions are f0 (7-step f0 continuum with 10 ms VOT), asp (7-step f0 continuum with 70 ms VOT), and breathy (7-step f0 continuum with 10 ms VOT and breathy voicing). Error bars indicate 95% average confidence intervals.

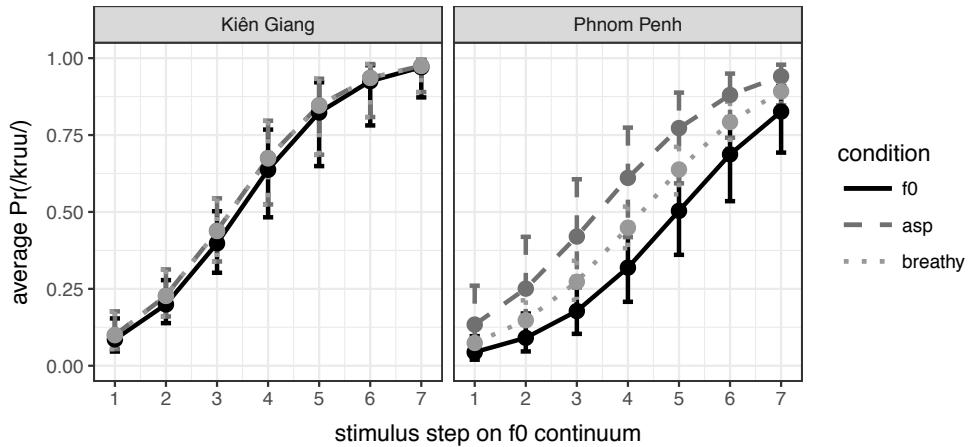


Table 4: Summary of fixed effects for a GLMM fit to Kiên Giang perceptual response data (with some participants excluded; see text). STIMULUS STEP and CONDITION are fixed effects, and the random intercepts for SUBJECT include random slopes for both terms. The coefficient estimate for STIMULUS STEP represents a change in the log-odds of a /kru:/ response for a one-unit change along the f0 continuum in the baseline (f0) condition.

Predictor	Coef β	SE(β)	z	Pr(> z)
(Intercept)	0.56	0.32	1.780	0.08
stimulus step	0.98	0.17	5.712	<0.0001
condition=asp	0.17	0.12	1.370	0.17
condition=breathy	0.16	0.12	1.339	0.18

5 Discussion

Previous acoustic studies of the r>h shift in PP Khmer found colloquial productions of forms such as ក្រុ /kru:/ ‘teacher’ to be characterized by absence of /r/, a low-falling f0 contour, increased post-release aspiration, and breathier voicing relative to careful or reading productions. As seen in Section 3, in KG, Standard Khmer forms with /r/ are realized with a falling-rising f0 contour, but without substantial changes in vowel or voice quality, and without a shift to [h] in clusters. This is broadly consistent with the transcriptions given by Thạch (1999), although we found the pitch contour to be falling-rising rather than simply falling.⁸ These dialect-specific differences in acoustic realization are mirrored in the perceptual responses (Section 4): while PP listeners are sensitive to aspiration and voice quality cues, KG listeners are not.

⁸ Kirby (2014a) reported a falling contour accompanying the r>h shift in PP Khmer, whereas previous reports suggested a falling-rising contour. In this study, we found the opposite: that is, while previous literature describes a low or falling tone, our data show a falling-rising contour. As discussed in Kirby (2014a), the falling tone in that study may have arisen due to interaction with a prosodic boundary tone, due to the items being recorded in isolation; if Thạch (1999) based his transcriptions on isolated wordlist readings, this may also explain the discrepancy between his transcriptions and our findings, which are based on items in carrier phrase context. In other words, it is possible that the essential feature in both dialects is essentially one of lowered pitch, with any subsequent rise (or lack thereof) a result of interaction with intonational factors.

5.1 Source of the r>h shift

Previous proposals regarding the source of the r>h alternation and its accompanying phonetic properties in Khmer may be organized into three types, with the understanding that these three possibilities are not necessarily mutually exclusive:

1. *Contact.* This is suggested by Thạch (1999) and Nguyễn (2010), both of whom propose that heavy and sustained contact with tonal Vietnamese has contributed to monosyllabization and the emergence of a limited pitch-based contrast.
2. *Devoicing of [r].* Both Wayland and Guion (2005) and Kirby (2014a) assume that the genesis of this sound change was devoicing of a coronal trill. Wayland and Guion suggest that devoicing of /r/ may have conditioned a drop in transglottal airflow and, subsequently, a falling f0 contour, which may then have been reanalyzed by listeners as a falling tone. Kirby (2014a) argues that the explanation is fundamentally acoustic in nature: aspiration resulting from the devoicing of the trill may have created a percept of breathy voicing on the following vowel, simultaneously lowering both F1 (resulting in vowel raising) and f0 (resulting in pitch lowering). At the same time, however, the aspiration noise of the trill would be parsed as aspiration, either as part of the preceding consonant or as /h/ in absolute initial position.
3. *A coronal/dorsal rhotic isogloss.* Filippi (2006), focusing on the PP case, casts doubt on the phonetic plausibility of any account that seeks to derive forms such as [kà:], [kʰà:], [kʰɔ̄ː], etc. from /kra:/ directly. He proposes instead the existence of a historical [r] ~ [ɹ] isogloss: following a change of [ɹ] to its present-day realization of breathiness, close vowel, and lowered pitch, the [ɹ] pronunciation was marginalized and the modern pronunciation diffused, possibly first to Phnom Penh⁹ and thence to regions beyond. After this, [r] was re-introduced into dialects ‘qui n’ont jamais possédé une réalisation de ce type’ (2006:23), either via one of the dialects where historical [r] had been maintained, and/or due to influence of the orthography and the formal style of which it was emblematic.¹⁰ While Filippi does not provide a phonetic justification for why a uvular or pharyngeal realization would be more likely than a coronal one to lead to ‘voix relâchée’ and lowered pitch, he suggests that the assumption of a posterior constriction makes it ‘concevable de construire un modèle phonétique’ (2006: 22).

Contact explanations of course cannot be completely ruled out, but would need to explain why, given the extensive monosyllabization that is characteristic of the r>h dialects, pitch contrasts are (a) limited to such a restricted phonotactic environment but also (b) present in Khmer dialects that have not been in such intense contact with tonal languages (cf. Brunelle and Kirby 2015).

As evidence for the proposal that a stage of [ɹ] was involved, Filippi (2006) cites the example of the causative prefix *baN-*, where it can be seen that [r], along with [h] and [ʔ], count as velars for the purposes of a phonological process of nasal assimilation (Table 5). A similar pattern is observed with the nominalising prefix *aN-*, although this admits a few exceptions where /r/ is concerned (Haiman 2011:52 ff.). Nevertheless, the general pattern is quite robust.

Cross-linguistically, allophony and/or dialect variation between [r] and [ɹ] (or [ɹ̩], [χ]...) is not uncommon, and is found in a number of European languages including French (Fougeron and Smith 1993), Basque (Hualde and Ortiz 2003), Norwegian (Johnsen 2012), and Dutch (Sebregts 2014). Although no single acoustic feature unifying rhotics has been identified (Lindau 1985), Engstrand et al. (2007) provide evidence from Swedish that coronal and dorsal rhotics may have similar acoustic properties, and Solé (2002) argues that voiceless trills are perceptually similar to fricatives. These studies therefore suggest that there may exist a perceptual basis for variation between these realizations.

⁹ Huffman (1967:247) describes the pronunciation of /r/ in Phnom Penh as ‘a voiced uvular fricative (as opposed to smooth) spirant’.

¹⁰ Although in principle a change in either direction would be possible, in those cases that have been carefully studied it generally appears that a change from coronal to dorsal is *a priori* more plausible than the reverse (see e.g. Howell 1986 on Germanic). In the present case, this analysis might find support in the retention of coda [r] in Surin Khmer (Premsrirat 1994).

Table 5: *Prefixation with the causative baN-, showing place assimilation of the nasal.*
Transcriptions are from Headley et al. (1997).

ពេង	/paŋ/	'to be swollen'	បំពេង	/bampaŋ/	'to inflate'
កោង	/taŋ/	'to hang on to'	បន្តាន	/bantaŋ/	'to suspend'
លូន	/lien/	'to protrude'	បន្ទូន	/banlien/	'to stick out'
ចូល	/cool/	'to enter'	បញ្ចូល	/baŋcool/	'to insert'
កើត	/kaət/	'to be born'	បញ្កើត	/baŋkaət/	'to give birth'
រីន	/rien/	'to study'	បញ្ចីន	/baŋrien/	'to teach'
ហើយ	/haəy/	'to be finished'	បញ្ជើយ	/baŋhaəy/	'to finish, conclude'
អាច	/ʔaac/	'to be capable of'	បញ្ជាគ	/baŋʔaac/	'to embolden'

Variation of /r/ with [h] or [f] has also been documented, including in Brazilian Portuguese (possibly via a dorsal realization: Mateus and d'Andrade 2000; Rennicke 2015) and Dominican Spanish (Willis 2006). As in the Khmer case, these variants are generally quite salient and often signify social or geographical affiliations. Closer to home, a proto-Tai alveolar trill *r- can be reconstructed with some confidence, with a reflex of /h-/ in most Southwestern Tai languages include Lao, Thi Lue, and Phu Thai among others; moreover, proto-Tai *Cr- clusters became aspirated *C^h in some (Southwestern and Central Tai) dialects but are retained as C_l- or C_j- clusters in some Northern Tai languages (Pittayaporn 2009). Hall (2014) describes numerous Tai Lue loans into Muak Sa-aak, an Austroasiatic language spoken in eastern Shan State, in which the Lue forms have /h/ but the Muak Sa-aak borrowings have /r/, suggesting they were borrowed at a time when the Lue forms retained /r/ as well. A shift from [r] > [h] would thus seem to have some measure of typological support, although we cannot rule out the possibility that intermediate stages were involved.

Moreover, *pace* Filippi, the essential elements of the phonetic accounts seem to us to be just as plausible in a scenario where the phonetic feature complex is derived from spirantization of the rhotic, which could lead directly to a reduction in transglottal airflow (Wayland and Guion) and/or condition spectral degradation and breathiness on the following vowel (Kirby), both of which are associated with lower f0. Some articulatory evidence supporting such accounts may be provided by Hoole and Bombien (2014, 2017), who found that in /Cr/ clusters in French and German, peak glottal abduction occurs during the rhotic. This suggests that speakers of at least some languages may be actively aiming to increase the amount of voicelessness in mixed-voicing clusters.

Regardless of the assumed starting point ([v] or [r]), we are left to face several outstanding issues:

- (a) the apparent typological rarity of the development of a register-type feature complex from loss of a rhotic;
- (b) the localization of this sound change in Khmer to a single segment (/r/, sometimes when in absolute-initial position only, sometimes when in either initially or as C₂ in complex onsets); and
- (c) the considerable phonetic variation in the modern reflexes of /r/ in Khmer dialects.

Regarding (a), it is clear that there are many languages with dorsal rhotics, but none of them seem to be transphonologizing them into register-type complexes involving aspiration, voice quality, and/or pitch. One possibility is that such features may in fact be characteristic of rhotic allophones in languages such as Brazilian Portuguese, but have not been noted as such. On the other hand, as many Khmer dialects (including PP and KG) are characterized by significant monosyllabification, which has been historically associated with tonogenesis (Matisoff 1973), so this may play a role in explaining for the typology asymmetry.

This leads us to point (b), or why the change has, to date, only affected /r/. Pisitpanporn (1999) notes that in PP Khmer, the pitch movement is not always accompanied by a shift of r>h; for a form like បណ្តុះ /baarəy/ 'cigarette' he cites a range of attested variants including *pə.ray*, *pə.həy*, *pa.ray*, *pa.rəy*, *play*, *phəy*, *phəy...* If variants with a pitch movement were to acquire greater prestige and/or become more widespread, it is conceivable that the incipient pitch contrast could become dissociated from its historical source.

However, as this variable seems to have been a fairly stable feature of PP Khmer for several generations (Pisitpanporn 1994), there is not necessarily reason to expect that it will spread further.

Accounting for the dialect differences (c) is perhaps even more challenging. Kirby (2014b) sketches an account for the difference between the PP and KG realizations involving difference in attention to cue dimensions. This account hinges on variation in listeners' reinterpretation of the acoustic effects of the devoiced rhotic (Ohala 1981). If KG listeners parsed the acoustic effects of devoicing on the pitch of the following vowel, while at the same time failing to reinterpret the devoiced /r/ as an aspiration feature of the onset, this could account for the divergence in phonetic evolution between the two dialects.

The phonetic divergence between dialects also leads to the question of whether these differences represent stages of a single sound change in progress, or are the result of different trajectories with a common point of departure. The lack of vowel quality difference is KG consistent with the lack of an observed voice quality difference, but does this mean that KG Khmer once had, and subsequently lost, breathy voice quality in this environment? An answer to this question awaits a more comprehensive survey of Khmer dialects.

6 Conclusion

This study has examined the acoustic and perceptual properties of the r>h shift in the Khmer dialect spoken in Kiên Giang province, Vietnam. We found that words beginning with /r/ or /Cr/ in Standard Khmer were produced with lowered pitch, but without noticeable breathy voice quality or diphthongization. Similarly, in perception, listeners appeared to be attending solely to f0 differences, and not to other acoustic cues. These dialectal differences suggest that further study the r>h shift in a wider range of Khmer varieties may prove instructive for our understanding of rhotics, tonogenesis, and sound change in general. As Eugénie Henderson once remarked of the Khmer r>h shift,

This very odd case shows that there is still much to learn. (1982:22)

7 Acknowledgments

This work was funded in part by a 2011 Council of American Overseas Research Centers (CAORC) Senior Research Fellowship from the Center for Khmer Studies to James Kirby. Thanks to Marc Brunelle, Pittayawat Pittayaporn, Koen Sebregts, and Joseph (Deth) Thach for their thoughtful comments on an earlier draft of this work. We alone remain responsible for any errors of fact or interpretation. We also extend our thanks to the People's Committee of Giồng Riềng province, the clergy of the Cái Đuốc Giữa temple, and to all of the participants, without whom this work would not have been possible.

References

- Bates, Douglas, Martin Maechler, and Ben Bolker. 2014. *lme4: Linear mixed-effects models using Eigen and S4*. R package version 1.1-7.
- Behrens, Susan J., and Sheila E. Blumstein. 1988. Acoustic characteristics of English voiceless fricatives: A descriptive analysis. *Journal of Phonetics* 16: 295–298.
- Blankenship, Barbara. 2002. The timing of nonmodal phonation in vowels. *Journal of Phonetics* 30: 163–191. doi:10.1006/jpho.2001.0155.
- Boersma, Paul, and David Weenink. 2011. *Praat: doing phonetics by computer* (version 5.2.26).
- Brunelle, Marc, and James Kirby. 2015. Re-assessing tonal diversity and geographical convergence in Mainland Southeast Asia. In *Languages of Mainland Southeast Asia: The State of the Art*, ed. Nicholas J. Enfield and Bernard Comrie, 82–110. Berlin: Mouton de Gruyter.
- Đinh, Lư Giang. 2011. Tình hình song ngữ Khmer-Việt tại đồng bằng sông Cửu Long: một số vấn đề lý thuyết và thực tiễn [Khmer-Vietnamese bilingualism in the Mekong Delta: theoretical and practical issues]. PhD dissertation, Ho Chi Minh City University of Social Sciences and Humanities.
- Đinh, Lư Giang. 2015. Các đặc điểm chính của song ngữ Khmer-Việt vùng Nam Bộ [The main features of Khmer-Vietnamese bilingualism in the South]. *Ngôn ngữ & Đời sống* 4: 81–88.

- Engstrand, Olle, Johan Frid, and Björn Lindblom. 2007. A perceptual bridge between coronal and dorsal /r/. In *Experimental approaches to phonology*, ed. Maria-Josep Solé, Patrice Speeter Beddor, and Manjari Ohala, 175–191. Oxford: Oxford University Press.
- Esposito, Christina M., and Sameer ud Dowla Khan. 2012. Contrastive breathiness across consonants and vowels: A comparative study of Gujarati and White Hmong. *Journal of the International Phonetic Association* 42: 123–143. doi:10.1017/S0025100312000047.
- Ferlus, Michel. 1989. Sur l'origine géographique des langues Viet-Muong. *Mon-Khmer Studies* 18–19: 52–59.
- Ferlus, Michel. 1992. Essai de phonétique historique du khmer. *Mon-Khmer Studies* 21: 57–89.
- Filippi, Jean-Michel. 2006. Norme et phonétisme dans le Cambodge moderne. *Udaya* 7: 1–31.
- Filippi, Jean-Michel, and Chan Vicheth Heap. 2016. *Khmer pronouncing dictionary: Standard Khmer and Phnom Penh dialect*. Phnom Penh: UNESCO, Éditions KAM.
- Fougeron, Cécile, and Caroline L. Smith. 1993. French. *Journal of the International Phonetic Association* 23: 73–76. doi:10.1017/S0025100300004874.
- General Statistics Office of Vietnam. 2010. *The 2009 Vietnam population and housing census: Major findings*. Hanoi: General Statistics Office of Vietnam.
- Gordon, Matthew, and Peter Ladefoged. 2001. Phonation types: a cross-linguistic overview. *Journal of Phonetics* 29: 383–406. doi:10.006/jpho.2001.0147.
- Hà, Văn Tân. 1986. Óc Eo: những yếu tố nội sinh và ngoại sinh [Óc Eo: endogenous and exogenous factors]. *Tạp chí khoa học xã hội Việt Nam* 1–2: 91–101.
- Haiman, John. 2011. *Cambodian*. Amsterdam: John Benjamins.
- Hall, Elizabeth. 2014. Impact of Tai Lue on Muak Sa-aak phonology. *Mon-Khmer Studies* 43: 24–30.
- Headley, Robert K., Rath Chim, and Ok Soeum. 1997. *Cambodian-English dictionary*. Dunwoody Press.
- Henderson, Eugénie J. A. 1952. The main features of Cambodian pronunciation. *Bulletin of the School of Oriental and African Studies* 14: 149–174.
- Henderson, Eugénie J. A. 1982. Tonogenesis: some recent speculations on the development of tone. *Transactions of the Philological Society* 80: 1–24.
- Hillenbrand, James, Ronald A. Cleveland, and Robert L. Erickson. 1994. Acoustic correlates of breathy vocal quality. *Journal of Speech, Language, and Hearing Research* 37: 769–778.
- Hoole, Philip, and Lasse Bombien. 2014. Laryngeal–oral coordination in mixed-voicing clusters. *Journal of Phonetics* 44: 8–24. doi:10.1016/j.wocn.2014.02.004.
- Hoole, Philip, and Lasse Bombien. 2017. A cross-language study of layngeal-oral coordination across varying prosodic and syllable-structure conditions. *Journal of Speech, Language, and Hearing Research* 60: 525–539. doi:10.1044/2016_JSLHR_S-15-0034.
- Howell, Robert B. 1986. Tracing the origin of uvular R in the Germanic languages. *Folia Linguistica Historica* 20: 317–350. doi:10.1515/flih.1986.7.2.317.
- Hualde, José Ignacio, and de Urbina Jon Ortiz, ed. 2003. *A grammar of Basque*. Berlin: Mouton de Gruyter.
- Huffman, Franklin E. 1967. An outline of Cambodian grammar. PhD dissertation, Cornell University.
- Iseli, Markus, Yen-Liang Shue, and Abeer Alwan. 2007. Age, sex, and vowel dependencies of acoustic measures related to the voice source. *The Journal of the Acoustical Society of America* 121: 2283–2295. doi:10.1121/1.2697522.
- Jenny, Matthias, and Patrick McCormick. 2015. Old Mon. In *The handbook of Austroasiatic languages*, ed. Paul Sidwell and Mathias Jenny, 519–552. Leiden: Brill.
- Johnsen, Sverre Stausland. 2012. A diachronic account of phonological unnaturalness. *Phonology* 29: 505–531. doi:10.1017/S0952675712000243.
- Jongman, Allard, Ratree Wayland, and Serena Wong. 2000. Acoustic characteristics of English fricatives. *The Journal of the Acoustical Society of America* 108: 1252–1263.
- Kirby, James. 2014a. Incipient tonogenesis in Phnom Penh Khmer: Acoustic and perceptual studies. *Journal of Phonetics* 43: 69–85. doi:10.1016/j.wocn.2014.02.001.

- Kirby, James. 2014b. Incipient tonogenesis in Phnom Penh Khmer: Computational studies. *Laboratory Phonology* 5: 195–230. doi:10.1515/lp-2014-0008.
- Kirby, James, and Đinh Lư Giang. 2017a. On the r>h shift in Kiên Giang Khmer: audio recordings, 2011 [sound]. doi:10.7488/ds/2075.
- Kirby, James, and Đinh Lư Giang. 2017b. On the r>h shift in Kiên Giang Khmer: supplementary materials. doi:<http://dx.doi.org/10.7488/ds/2242>.
- Kuznetsova, Alexandra, Per Bruun Brockhoff, and Rune Haubo Bojesen Christensen. 2016. *lmerTest: Tests for linear mixed effects models*. R package version 2.0-33.
- Leang, Sam Eng. 2011. ភាសាខ្មែរសំភាសាប់ប្រព័ជននៃក្នុងភូមិក្រោចតាព្វំង យំរួមិច្ច ស្រុកណ្ឌាល ខេត្តកណ្តាល [The Khmer dialect spoken in Preak Ta Prang village, Kandal province]. MA thesis, Royal University of Phnom Penh.
- Lenth, Russell V. 2016. Least-squares means: the R package lsmeans. *Journal of Statistical Software* 69: 1–33. doi:10.18637/jss.v069.i01.
- Lindau, Mona. 1985. The story of /r/. In *Phonetic linguistics: Essays in honor of Peter Ladefoged*, ed. Victoria Fromkin, 157–168. Orlando, FL.
- Mai, Ngọc Chù. 1988. Vài nhận xét về ngôn ngữ hội thoại của người Khmer Phnômpênh [Some remarks on the colloquial language of Phnom Penh Khmer]. In *Tiếng Việt và các ngôn ngữ Đông Nam Á*, 27–29. Hà Nội: Nhà Xuất Bản Khóa Học Xã Hội.
- Martini, François. 1946. Aperçu phonologique du cambodgien. *Bulletin de la Société de Linguistique de Paris* 42: 112–131.
- Mateus, Maria Helena, and Ernesto d'Andrade. 2000. *The phonology of Portuguese*. Oxford: Oxford University Press.
- Matisoff, James A. 1973. Tonogenesis in Southeast Asia. In *Consonant types and tone*, ed. Larry M. Hyman, 73–95. Los Angeles: University of Southern California.
- Minegishi, Makoto. 1986. On Takeo dialects of Khmer: phonology and word list. *Journal of Asian and African Studies* 31: 130–157.
- Nguyễn, Thị Huệ. 2008. Một số dấu hiệu về tiếp xúc ngôn ngữ Việt–Khmer tại tỉnh Trà Vinh [Evidence of interaction between Kinh and Khmer Languages in Tra Vinh Province]. *Tạp chí Khoa học* 13: 76–86.
- Nguyễn, Thị Huệ. 2010. Tiếp xúc ngôn ngữ giữa tiếng Khmer với tiếng Việt (trường hợp tỉnh Trà Vinh) [Language contact between Khmer and Vietnamese in Tra Vinh province]. PhD dissertation, Ho Chi Minh City University of Social Sciences and Humanities.
- Noss, Richard B. 1966. The treatment of */r/ in two modern Khmer dialects. In *Studies in comparative Austroasiatic linguistics*, ed. Norman H. Zide, 89–95. London: Mouton & Co.
- Ohala, John J. 1981. The listener as a source of sound change. In *Proceedings from the 17th Annual Meeting of the Chicago Linguistic Society, Volume 2: Papers from the Parasession on Language and Behavior*, ed. Carrie S. Masek, Roberta A. Hendrick, and Mary Frances Miller, 2:178–203. Chicago: Chicago Linguistic Society.
- Pain, Frederic. 2014. An anthropological approach on Khmer dialectology: Language, Buddhism, and ethnicity. hal-01009553.
- Phoeun, Mak. 1995. *Histoire du Cambodge de la fin du XVI^e siècle au début du XVIII^e siècle*. Paris: Presses de l'École française d'Extrême-Orient.
- Pisitpanporn, Naraset. 1994. On the r > h shift in Phnom Penh Khmer. *Mon-Khmer Studies* 24: 105–113.
- Pisitpanporn, Naraset. 1999. A note on colloquial Phnom Penh Khmer. In *Papers from the ninth annual meeting of the Southeast Asian Linguistics Society*, ed. Graham Thurgood, 243–248. Arizona State University: Program for Southeast Asian Studies.
- Pittayaporn, Pittayawat. 2009. The phonology of proto-Tai. PhD dissertation, Cornell University.
- Premsrirat, Suwilai. 1994. Phonetic variation of final trill and final palatals in Khmer dialects of Thailand. *Mon-Khmer Studies* 24: 1–26.

- Premsrirat, Suwilai. 1997. Linguistic contributions to the study of the Northern Khmer language of Thailand in the last two decades. *Mon-Khmer Studies* 27: 129–136.
- Rennicke, Iris. 2015. Variation and change in the rhotics of Brazilian Portuguese. PhD dissertation, University of Helsinki.
- Sakamoto, Yasuyuki. 1968. The standard Khmer language and its Phnom Penh dialect. *Tonan Aija Kenkyu* 6: 48–78.
- Sebregts, Koen. 2014. The sociophonetics and phonology of Dutch r. Utrecht: LOT, Netherlands Graduate School of Linguistics.
- Sidwell, Paul. 2009. *Classifying the Austroasiatic languages: history and state of the art*. LINCOM Studies in Asian Linguistics 76. Munich: LINCOM Europa.
- Solé, Maria-Josep. 2002. Aerodynamic characteristics of trills and phonological patterning. *Journal of Phonetics* 30: 655–688. doi:10.1006/jpho.2002.0179.
- Stark, Miriam T. 1998. The transition to history in the Mekong delta: a view from Cambodia. *International Journal of Historical Archaeology* 2: 175–203.
- Taylor, Philip. 2013. *The Khmer lands of Vietnam: Environment, cosmology and sovereignty*. Honolulu: University of Hawaii Press.
- Thạch, Ngọc Minh. 1999. Monosyllabization in Kiengiang Khmer. *Mon-Khmer Studies* 29: 81–95.
- Vickery, Michael. 2003. Funan reviewed: deconstructing the ancients. *Bulletin de l'Ecole française d'Extrême-Orient* 90: 101–143. doi:10.3406/befeo.2003.3609.
- Vickery, Michael. 2011. “1620”, a cautionary tale. In *New perspectives on the history and historiography of Southeast Asia: Continuing explorations*, ed. Michael Arthur Aung-Thwin and Kenneth R. Hall, 157–166. London: Routledge.
- Wayland, Ratree P., and Susan G. Guion. 2005. Sound change following the loss of /r/ in Khmer: a new tonogenetic mechanism? *Mon-Khmer Studies* 35: 55–82.
- Wayland, Ratree P., and Susan G. Guion. 2007. Tonogenesis in Khmer. In *SEALSXII: Papers from the 12th meeting of the Southeast Asian Linguistic Society (2002)*, ed. Ratree P. Wayland, John Hartmann, and Paul Sidwell, 145–152. Canberra: Pacific Linguistics.
- Willis, Erik W. 2006. Trill variation in Dominican Spanish. An acoustic examination and comparative analysis. In *Selected proceedings of the 9th Hispanic Linguistics Symposium*, 1:121–131. Somerville, MA: Cascadilla Proceedings Project.

Appendix: Wordlist

IPA values are for canonical Standard (Central) Khmer pronunciations, following Headley et al. (1997).

Khmer	IPA	Vietnamese	Gloss
ព្រោ	/kru:/	giáo viên	‘teacher’
គុ	/ku:/	đôi	‘pair’
ក្រា	/kra:/	nghèo	‘poor’
ខ	/kha:/	kho	‘to stew in fish sauce’
កា	/ka:/	(cái) cỗ	‘neck’
រីន	/rien/	học	‘to study, learn’
ហិន	/hien/	dám	‘to dare’
រឹង	/riŋ/	cứng	‘hard’
ហីង	/hiŋ/	bàn thờ	‘altar’
ស្រា	/sra:/	ruou	‘alcohol’
សា	/sa:/	cuốn	‘(to) roll’
ត្រា	/tra:/	đóng dấu	‘(to) seal, stamp’
តា	/ta:/	ông	‘grandfather’
ថា	/tha:/	kêu, nói	‘to call, tell’
ត្រូ	/tru:/	cái nơm ca	‘kind of fish trap’
ធូ	/thu:/	lỏng	‘fluid’
ទុ	/tu:/	tủ (đè quần áo)	‘closet, cupboard’
សក់	/sak/	tóc	‘hair’
ស្រក់	/srak/, /srak/	nước ròng	‘to drip, draw down (tide)’

Reviewed: Received 26 May 2017, revised text accepted 11 Nov 2017, published 10 Dec 2017

Editors: Editor-In-Chief Dr Mark Alves | Managing Eds. Dr Paul Sidwell, Dr Nathan Hill, Dr Sigrid Lew