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*Tone production, tone perception and Kammu tonogenesis**

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The Northern and Western dialects of the Mon-Khmer language Kammu use fundamental frequency to distinguish words, while the Eastern dialect relies on the contrastive voicing of initial consonants to distinguish words which display an F0 contrast in the other dialects. The production and perception of tones in the three dialects is investigated, using recordings and perception tests. As expected, Northern and Western Kammu speakers do use F0 to distinguish words, as seen both in their production and in perception tests, which show that they could distinguish small F0 differences. In contrast, Eastern Kammu speakers neither produce nor perceive F0 differences at the lexical level. Furthermore, the voiceless and voiced stops in Eastern Kammu cause smaller F0 perturbations in the following vowel than might be expected for a language undergoing tonogenesis. The significance of these results for tonogenesis is discussed, as well as their relevance for the notion of 'tone language'.

1 Background

Much work on tonogenesis has been concerned with describing languages in which high and low tones have developed after initial voiceless and voiced consonants respectively. In many of these languages, the voiceless–voiced contrast is lost and replaced by high and low tones, manifested phonetically by relatively higher and lower fundamental frequency (Matisoff 1973, Hombert 1978, Painter 1978, Hombert *et al*. 1979, Maddieson 1984). The tones are also frequently accompanied by concomitant voice-quality differences, such as clear *vs*. breathy or tense *vs*. lax

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voice (Lee 1983, Luangthongkum 1987, 1989, 1990). In some languages, including the Mon-Khmer languages Wa (Paraok), Lamet and Khmer, the merger of voiceless and voiced initial consonants has led to voice-quality contrasts where F0 is not involved (Svantesson 1983b, 1993, Maddieson & Ladefoged 1985, Watkins 1999, 2002, Wayland & Jongman 2003) or to vowel-quality contrasts (Henderson 1952).

Kammu provides us with a particularly interesting object of study for the development of tone. Some dialects of this language have developed a tone contrast which corresponds to a contrast between voiceless and voiced initial consonants in other dialects. Thus Kammu is a language in which the process of acquiring tones is still ongoing (see Svantesson 1983a, 1989, 2001, Premsrirat 2003).

The Kammu language, which belongs to the Mon-Khmer branch of the Austroasiatic language family, is spoken by some 600,000 people, most of them in northern Laos. There are three main dialects, Eastern, Northern and Western Kammu, whose distribution is shown on the map of Northern Laos in Fig. 1. Eastern Kammu is non-tonal, and retains the original contrasts between voiceless /p, t, c, k/ and voiced /b, d, ɟ, g/ stops and voiceless /m̥, n̥, ɲ̥, ŋ̊, l̥, r̥, w̥, j̥/ and voiced /m, n, ɲ, ŋ, l, r, w, j/ sonorants. In Northern and Western Kammu, syllables with originally voiceless and voiced initials have developed high and low tone respectively. In Northern Kammu, the consonants of each pair have merged into the unmarked member, so that the stops have become voiceless and the sonorants voiced. Thus the voiceless–voiced consonant contrast has been replaced by a high–low tone contrast (see Fig. 2 below for an illustration of the F0 difference). In Western Kammu, the voiceless sonorants have become voiced, just as in Northern Kammu, but the voiced stops have become aspirated voiceless, contrasting both segmentally and tonally with the original unaspirated voiceless stops, which are retained as such in all dialects. There are original aspirated stops as well, although they are not very frequent, most of them occurring in loans from Lao. The original aspirates did not change, and gave rise to high tone in Northern and Western Kammu. Thus, Northern Kammu words have a tone contrast if they begin with a sonorant or a voiceless unaspirated stop, but words with an aspirated stop always have high tone; for Western Kammu, words beginning with sonorants or aspirated stops have contrasting tone, but those with a voiceless unaspirated stop always have high tone. The situation is illustrated by the words in (1).

(1) *Words illustrating Kammu tonogenesis*

Eastern	*Northern*	*Western*	
taaŋ	táaŋ	táaŋ	‘pack’
daaŋ	tàaŋ	tʰàaŋ	‘lizard’
tʰaaŋ	tʰáaŋ	tʰáaŋ	‘to clear’
r̥aaŋ	ráaŋ	ráaŋ	‘tooth’
raaŋ	ràaŋ	ràaŋ	‘flower’

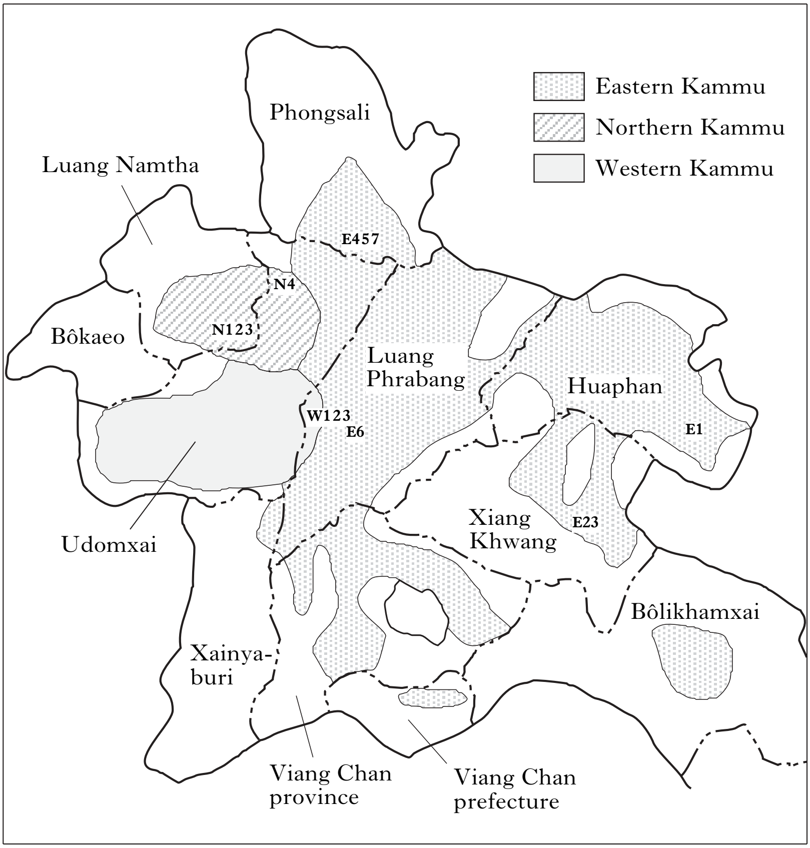

Figure 1
Approximate distribution of Kammu in the northern provinces of Laos (according to Chazee 1995). The Eastern (non-tonal) dialects are called Uu and Mee in Kammu, the Northern dialects are Yùan, Lɨ̀ɨ (or Cwàa) and Kwɛ̀ɛn, and Western is Rɔ̀ɔk. The approximate locations of the home villages of the speakers are shown on the map (cf. Table I). We have no exact knowledge of the tone development in the Krɔ́ɔŋ dialect spoken along the Mekong river in the southern part of Udomxai province. It is tentatively included in the Western group in the map.

Except for these changes, there are only marginal differences between the dialects, and speakers of all dialects can understand each other without difficulty. Most speakers seem to be rather unaware of the phonological differences, while lexical differences are more salient. For example, negation, which is /pə́ə/ or /ʔàl/ in Northern Kammu, /kʰát/ in Western Kammu and /ʔam/ in Eastern Kammu, is used as a shibboleth for distinguishing the dialects.

The principal phonetic feature characterising the tones in both Northern and Western Kammu is fundamental frequency (Gårding & Lindell

1977). A contrast between clear and breathy voice, combined with a pitch contrast, has been reported for some Kammu dialects by Premsrirat (2003). Although we cannot discount the possibility that some voice-quality difference may occur between the tones in the Kammu dialects recorded by us in Laos, none of our speakers shows any major differences of the kind found in other Mon-Khmer languages such as Wa.

It is impossible to know exactly when tonogenesis took place in Northern and Western Kammu, although the numerous loanwords from Tai languages give some indications. The phonology of the oldest layers of loans shows that they were borrowed before tonogenesis took place in Kammu, and comparison with reconstructions of Proto-Tai and its major branches (Li 1977) shows that they were borrowed at the Proto-south-western Tai stage (Svantesson 2005), before the modern south-western Tai languages such as Lao, Lü and Thai started to differentiate, and also before the creation of writing systems for these languages in the 13th century. It can thus be said with some confidence that Kammu tonogenesis is no older than about 700 years, but a more exact time cannot be given. We have no indications, however, that people in Northern or Western Kammu-speaking villages have been speaking non-tonal dialects within living memory.

Although the historical developments in the different dialects cannot be traced in any written sources or by strict reconstructions, the following somewhat speculative scenario for the development of words with an initial stop can be suggested (cf. also Premsrirat 2003):

(i) Voiced stops became devoiced, leading to a contrast between clear voice and relatively high pitch *vs.* breathy voice and relatively low pitch. This stage is not found in our recordings, but has been reported for some Kammu dialects by Premsrirat (2003).

(ii) For some dialects, pitch was taken as the main cue for the contrast, and the voice-quality contrast disappeared (Northern Kammu).

(iii) For other dialects, breathiness was perceived as a property (i.e. voiced aspiration) of the consonant rather than of the following vowel. At a later stage, the stop became an ordinary voiceless aspirated stop, and the voice-quality difference disappeared, but the pitch contrast remained (Western Kammu).

2 Introduction to the present study

As far as we know, Kammu is the only well-described language currently in the process of acquiring tones, such that the only major difference between its dialects is that some of them have tones while others have not. There are other languages where one dialect is tonal and others are non-tonal, for instance Tibetan, but in these cases there are other major phonological differences between the dialects as well (Huang 1995).

A detailed investigation of the production and perception of tone in different Kammu dialects is thus not only of interest as documentation of the language, but may also lead to a better understanding of tonogenesis, one of the most important processes in the shaping of the Southeast Asian language type (see e.g. Matisoff 1973, Svantesson 2001).

2.1 Production study

The main objective of the production study was to examine tonal differences between the dialects as phonetically realised by F0. This was to be carried out by measuring F0 in systematically varied minimal-pair test words in a carrier sentence in the three dialects. Our hypothesis was that there would be no significant difference between F0 in minimal pairs with voiced and voiceless initial consonants in the Eastern dialect, while we would find significant F0 differences between the corresponding words in the Northern and Western dialects.

A second objective of the study was to measure differences in the stop consonants in the minimal pairs in the three dialects. We measured the duration of the initial consonants in the minimal pairs. Our hypothesis was that we would find significant durational differences in the Eastern dialect (due to the voiced–voiceless consonant contrast) but not in the Northern and Western dialects.

Since the tone contrast is accompanied by an aspiration contrast in the Western Kammu test words with an initial stop, we additionally measured aspiration for these words, as defined by voice onset time (VOT). We expected to find longer VOT for the vowels with low tone than for the vowels with high tone. The Northern dialect is not analysed as having an aspiration contrast, but since Speaker N1's productions were used in the perception study (see §4), his VOT was measured as well.

Finally, it has often been proposed that tonogenesis of the type found in Kammu is due to microprosodic effects of voiced and voiceless initial consonants, causing F0 to be higher immediately after a voiceless consonant than after a voiced one (see e.g. Hombert *et al*. 1979). This effect is then perceived as a property belonging to the vowel and produced as a tonal difference (Ohala 1993). The actual mechanism causing this F0 perturbation is controversial (Ohala 1978), and was first attributed to aerodynamic factors caused by a presumed greater airflow after the release of a voiceless stop than after a voiced one (see Ladefoged 1967). More recently, physiological factors have been introduced as an explanation, factors which presumably result in greater tension on the vocal folds during voiceless than voiced stop production (see Hombert 1978, Löfqvist *et al*. 1989, Ohala & Sprouse 1999, Gussenhoven 2004). In the Kammu case, it can be expected that the voiceless *vs*. voiced initial consonant contrast in the Eastern dialect is accompanied by a relatively higher *vs*. relatively lower F0 fall in the beginning of the following vowel or sonorant, but that this effect should not be found in the tonal Northern and Western dialects. To test this, we measured the F0 fall at the beginning of the vowel in each dialect.

2.2 Perception study

In an earlier perception study on Kammu, Gandour *et al*. (1978) reported that speakers of Northern Kammu can use differences in F0 to perceive tonal differences. The main goal of our perception study was not only to corroborate these findings, but also to test if speakers of the Western tonal dialect and the Eastern non-tonal dialect can use F0 as a cue for differentiating word pairs, such as 'eagle' and 'stone', spoken by speakers of the Northern dialect where these words differ only in tone, as in (2) below. If this is so, we also want to compare sensitivity to pitch levels in listeners of the three dialects in our study. Our expectations were that Northern and Western Kammu listeners would be able to reliably categorise stimuli which systematically differ in pitch levels into two separate groups, 'eagle' and 'stone'. We expected the Eastern Kammu listeners to use the initial consonant as the main criterion and to therefore categorise all the stimuli as 'eagle'. The results were expected to show the degree of tonal awareness of the tonal and non-tonal speakers, and to give an indication of the stage of tonal development in the three dialects.

3 Production data

3.1 Speech material

Material consisting of six test words (three minimal pairs, each in two different carrier sentences), was recorded from 14 speakers of Kammu (7 Eastern, 4 Northern, 3 Western). To balance the possible influence from the tone of the word following the test word, different final words were used in the carrier sentence, *viz*. /n̥am/ ~ /nám/ 'big' and /ɲɛʔ/ ~ /nɛ̀ʔ/ 'small', which have different tones in Northern and Western Kammu. The carrier sentences are listed in (2).

(2) *Material for the production investigation*

a. *Test words*

Eastern	*Northern*	*Western*		*category*
klaaŋ	kláaŋ	kláaŋ	'eagle'	K H
glaaŋ	klàaŋ	k^{h}làaŋ	'stone'	K L
r̥aaŋ	ráaŋ	ráaŋ	'tooth'	R H
raaŋ	ràaŋ	ràaŋ	'flower'	R L
taaŋ	táaŋ	táaŋ	'pack'	T H
daaŋ	tàaŋ	t^{h}àaŋ	'lizard'	T L

b. *Carrier sentences*

Eastern	*Northern*	*Western*
gii məh __ n̥am	kìi mə̀h __ nám	k^{h}ìi mə̀h __ nám
gii məh __ ɲɛʔ	kìi mə̀h __ nɛ̀ʔ	k^{h}ìi mə̀h __ nɛ̀ʔ

'This is a big __.'

'This is a small __.'

In the remainder of this paper, we use the dialect-neutral symbols K, T and R to represent the initial consonant categories /k ~ g ~ k^h/, /t ~ d ~ t^h/ and /r ~ r̥/ respectively. H and L are used for the categories realised as high and low tone in Northern and Western Kammu, and as voiceless and voiced initial consonants in Eastern Kammu.

3.2 Speakers

Data on the speakers is given in Table I. All speakers live in Laos, except N1, who has been living in Sweden since 1974. This speaker, Damrong Tayanin, has been engaged in full-time research on the Kammu language and culture during his stay in Sweden, and speaks Kammu on a daily basis. He was recorded in Lund in 1995. The other recordings were made in Vientiane, Luang Phrabang city and Ban Tapaen village (Luang Phrabang province) in Laos in January 1996. Like most Kammu, all recorded speakers are at least bilingual, with Kammu as their first language, and Lao as their second, learned at school age or later. They have also had many contacts with speakers of Kammu dialects other than their own. All speakers are literate in Lao.

		sex	age	birthplace (district and province)
Eastern Kammu	E1	M	49	Samneua, Huaphan
	E2	M	26	Meuang Khun, Xiang Khwang
	E3	M	42	Meuang Khun, Xiang Khwang
	E4	M	45	Meuang Khwa, Phongsali
	E5	M	57	Meuang Khwa, Phongsali
	E6	M	50	Ban Nô, Luang Phrabang
	E7	F	38	Meuang Khwa, Phongsali
Northern Kammu	N1	M	57	Kaneung Phaet, Luang Namtha
	N2	M	40	Kaneung Phaet, Luang Namtha
	N3	M	35	Kaneung Phaet, Luang Namtha
	N4	M	53	Meuang Namô, Udomxai
Western Kammu	W1	M	31	Ban Tapaen, Luang Phrabang
	W2	F	29	Ban Tapaen, Luang Phrabang
	W3	F	40	Ban Tapaen, Luang Phrabang

Table I

The speakers. Birthplaces are shown in the dialect map in Fig. 1.

3.3 Recording procedure

Since Kammu is an unwritten language, the speakers were presented with the 12 sentences (the six test words in the two carrier sentences) written in

Lao. They were asked to translate each sentence into their native language and repeat them five times. The three middle repetitions were used for analysis. This procedure was usually repeated once or twice in order to get fluent renderings, and also to be able to find three examples of each sentence that were reasonably free from the noise of chickens, motorcycles or children, which were often present during the recording sessions. By practical necessity, the sentences were always presented in the order given in (2). Each word was first read in the carrier sentence ending in ‘big’, and immediately after that it was read in the sentence ending in ‘small’.

Since the sentences were presented in Lao, there was some minor segmental variation in their Kammu form. Speaker E5 used the Lao loanword /mɛɛn/ as copula (instead of /məh/). The word ‘small’ is /ɲɛ̀ʔ/ (not /nɛ̀ʔ/) for speakers N4 and W2. Speaker N4 pronounced the word ‘tooth’ with a short vowel: /ráŋ/.

Speaker E6 demonstrated greater deviation. Among other things, he used the word /dɛk/ instead of /n̥am/ for ‘big’. Additionally, we suffered technical difficulties with this speaker’s recordings of /klaaŋ/. In view of these difficulties, we decided to eliminate speaker E6 from the analysis.

3.4 Analysis procedure

The recordings were analysed acoustically using *ESPS-Waves+* software. Fundamental frequency analysis was carried out by measuring F0 in the tone-carrying part of the test words. An an illustration, examples of F0 curves for one tonal and one non-tonal speaker are shown in Fig. 2.

The tone-carrying part of a syllable was taken to be its voiced segments, excluding the initial consonant, i.e. [laːŋ] for the words /klaaŋ/ ~ /glaaŋ/, and [aːŋ] for the words /taaŋ/ ~ /daaŋ/ and /raaŋ/ ~ /r̥aaŋ/. The [l] was included in the tone carrier because possible microprosodic effects of the initial voiceless ~ voiced consonants can be expected already in the [l], and also because an earlier study (House & Svantesson 1996) suggested that voiced sonorant non-initial members of initial consonant clusters should be regarded as included in the tone-carrier in Thai, another tone language spoken in the Southeast Asian area.

Since the Kammu tones are fairly flat, the average fundamental frequency over the middle third of the tone-carrying part of each recording of each test word was used in the analysis. In order to obtain a time-normalised expression of the fundamental frequency contour, the following procedure was used. The tone-carrying part of the test word was divided into six equal parts, and the average F0 over each sixth was computed. Each of these F0 means was averaged over the six recordings of each test word. In this way, stylised average tone curves, normalised for duration, were obtained.

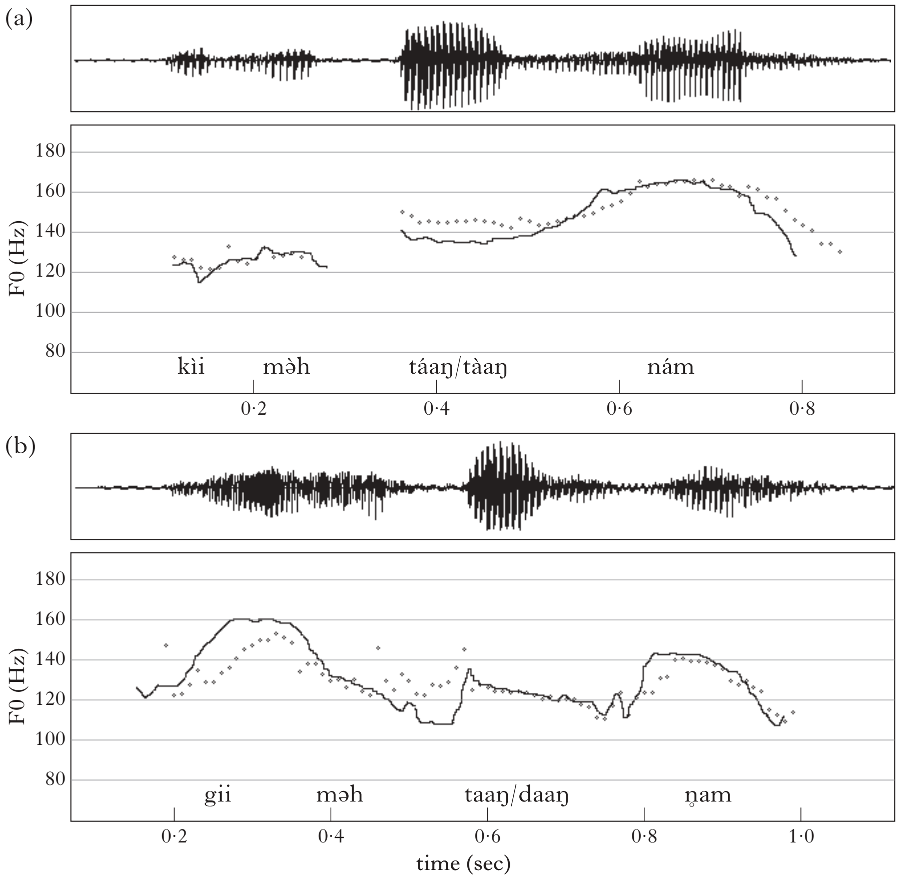

Figure 2

Examples of F0 curves from (a) tonal (speaker N1) and (b) non-tonal (speaker E1) Kammu. The curves illustrate the F0 difference between /táaŋ/ (dotted line) and /tàaŋ/ (solid line) for N1, and the absence of tone differences for speaker E1's corresponding words /taaŋ/ (dotted line) and /daaŋ/ (solid line). The waveforms are from /táaŋ/ and /taaŋ/ respectively, with the F0 tracings synchronised at vowel onset of the test words.

As explained in the introduction, the H and L categories for words with initial stops are analysed as involving a contrast between voiceless and voiced consonants in Eastern Kammu. This contrast has been lost, and replaced by a tone contrast in Northern Kammu, while in Western Kammu there is a tone contrast as well as a contrast between voiceless unaspirated and voiceless aspirated stops. The voiceless–voiced contrast in Eastern Kammu and its absence in Northern Kammu is clearly audible (and visible in waveform plots and spectrograms), but in order to quantify it, the total duration of the initial stops (from the beginning of the occlusion phase to the beginning of the following vowel or sonorant) was measured. Originally voiced stops developed into aspirates in Western Kammu, so the VOT, interpreted as the duration of the aspiration, was also measured for the Western speakers.

To test microprosodic effects of voiced and voiceless initial consonants, we measured the initial F0 fall at the beginning of the vowel in each dialect. This was quantified by representing the initial fall with the difference between the average F0 over the first 15 ms of the tone-carrying segment of the test word and the average F0 over the interval from 35 ms to 50 ms. For these measurements, absolute time was used, since microprosodic effects are defined in terms of the vowel onset and should not be affected by differences in vowel duration.

For the production study, analysis of variance was performed within each dialect, with the H *vs.* L category and initial consonant (i.e. the segmental categories K, T, R) as fixed factors (labelled Tone and Cons respectively) and Speaker as a random factor. Tests for the effects of the factors Tone and Cons, and the interactions Tone × Cons and Tone × Cons × Speaker are shown below in Tables II–V for different dependent variables (F0, duration, VOT and initial fall). The results are given as the F-distributed test statistic with its numbers of degrees of freedom, and a p-value. For practical reasons, we have not been able to balance for the number of female and male speakers in the dialect samples, and since the results for the factor Speaker can be expected to depend crucially on the distribution of female/male speakers, at least for the variables involving F0, we have chosen not to include results for this factor in the tables.

3.5 Results

3.5.1 *Fundamental frequency*. Figure 3 shows stylised average tone curves normalised for duration for three speakers, one from each dialect area. As expected, the Northern and Western speakers (b, c) separate the H and L categories, while the Eastern speaker (a) mixes them. Most of the other speakers show a similar pattern.

The results of the analysis of variance for F0 are given in Table II. As expected, the factor Tone has no significant effect for Eastern Kammu ($p = 0{\cdot}254$), but does for Western Kammu ($p = 0{\cdot}011$). Northern Kammu does not conform to the expected pattern, however, since the p-value is slightly above the 0·05 level of significance ($p = 0{\cdot}062$). This is probably due to the rather large variation between speakers and the small F0 differences involved. Analysis of variance performed within each Northern speaker showed significant effects of Tone for each speaker: $F(1,30) = 153{,}5$ ($p < 0{\cdot}001$) for N1; $F(1,30) = 161{\cdot}4$ ($p < 0{\cdot}001$) for N2; $F(1,30) = 10{\cdot}4$ ($p = 0{\cdot}003$) for N3; $F(1,30) = 14{\cdot}6$ ($p < 0{\cdot}001$) for N4.

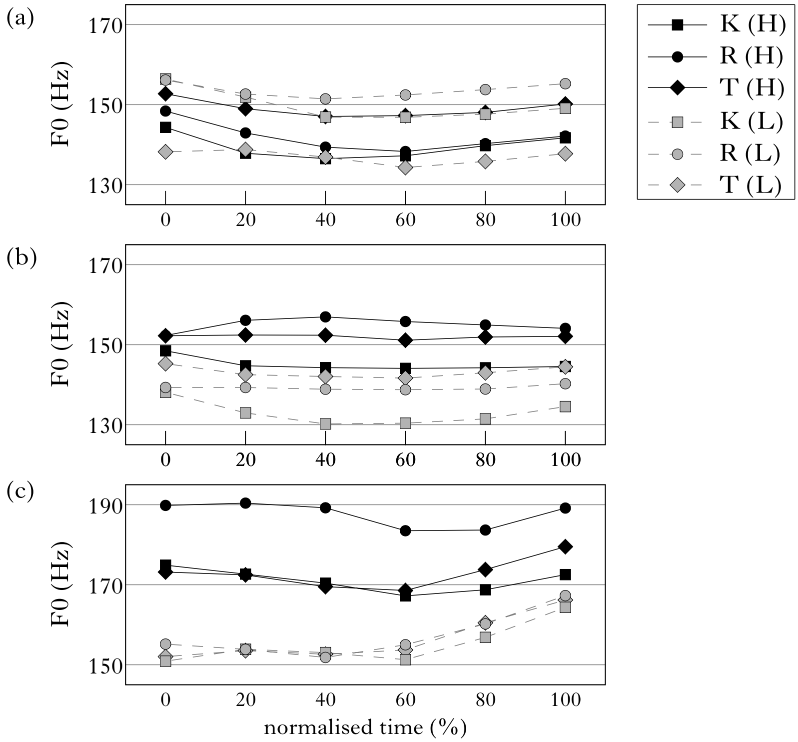

Figure 3

Stylised average tone curves for one speaker of each dialect. (a) Eastern (Speaker E2); (b) Northern (Speaker N2); (c) Western (Speaker W1).

As seen in Table IIb, all Northern and Western speakers follow the expected pattern that H category words have higher average F0 than L category words. The F0 difference between the two tones is quite small, the average ranging between 4 Hz and 25 Hz for the male Northern and Western speakers, and between 17 Hz and 25 Hz for the female speakers W2 and W3. It is also interesting to note that subject N3, who had the smallest average F0 difference, did not use F0 differences to distinguish the two categories in the perception test.

As seen in Table IIa, the factor Cons (initial consonant) has significant effects in all dialects. It cannot be excluded that this can be an effect of the recording situation: for practical reasons, all words with initial consonant of category K were recorded first, followed by those with R, and finally by those with T. For the Northern and Western dialects, this effect may also be due to the fact that speakers of these dialects usually make a larger average F0 difference for words beginning with [r] than for words beginning with a stop (cf. Fig. 3). Since Western Kammu, but not Northern

(a)	factor/ interaction	df_1	df_2	F	p
Eastern Kammu	Tone	1	5	1·7	0·254
	Cons	2	10	5·3	0·027*
	Tone × Cons	2	10	2·2	0·167
	Tone × Cons × Speaker	10	180	3·3	< 0·001*
Northern Kammu	Tone	1	3	8·4	0·062*
	Cons	2	6	8·6	0·017*
	Tone × Cons	2	6	5·3	0·047*
	Tone × Cons × Speaker	6	120	0·8	0·574
Western Kammu	Tone	1	2	89·5	0·011*
	Cons	2	4	33·6	0·003*
	Tone × Cons	2	4	7·2	0·047*
	Tone × Cons × Speaker	4	90	1·6	0·183

(b)

	H	L
E1	115	116
E2	141	145
E3	101	100
E4	119	125
E5	148	146
E7	207	209

	H	L
N1	129	104
N2	151	137
N3	146	142
N4	160	151

	H	L
W1	175	153
W2	216	199
W3	213	188

Table II

Fundamental frequency: (a) analysis of variance; (b) mean F0 (Hz) for the H and L categories for all speakers.

Kammu, has a segmental (aspiration) contrast in addition to the pitch contrast in the test words beginning with a stop, one might expect this effect to be more prominent in Western than in Northern Kammu, but this does not seem to be the case. This is probably related to the fact that, as seen in §1, there is actually a pitch contrast in words with aspirated stops in Western Kammu, involving those aspirates that developed in tonogenesis and those that existed before.

As explained above, different final words of the carrier sentence were used to balance the possible influence from the tone of the word following the test word. In most cases this had no influence on the F0 of the test word. Speaker N1 is an exception: his test words are on the average about 10 Hz higher before the high tone word /nám/ than before /nὲʔ/.

3.5.2 *Initial consonant duration.* The result is shown in Table III. As expected, the factor Tone has a significant effect on the duration of

(a)	factor/ interaction	df_1	df_2	F	p
Eastern Kammu	Tone	1	5	46·2	0·001*
	Cons	1	5	1·5	0·270
	Tone × Cons	1	5	0·6	0·466
	Tone × Cons × Speaker	5	120	4·1	0·002*
Northern Kammu	Tone	1	3	4·4	0·127
	Cons	1	3	0·2	0·670
	Tone × Cons	1	3	1·7	0·288
	Tone × Cons × Speaker	3	80	1·1	0·346
Western Kammu	Tone	1	2	1·5	0·344
	Cons	1	2	1·4	0·364
	Tone × Cons	1	2	5·7	0·139
	Tone × Cons × Speaker	2	60	1·5	0·284

(b)

	H	L
E1	110	58
E2	106	65
E3	99	31
E4	93	70
E5	90	27
E7	128	54

	H	L
N1	116	102
N2	75	63
N3	86	86
N4	91	90

	H	L
W1	70	72
W2	87	83
W3	118	101

Table III

Total consonant duration for initial stops: (a) analysis of variance; (b) mean duration (ms) for the H and L categories for all speakers.

initial stops in the Eastern dialect ($p = 0{\cdot}001$), and the average stop duration is much larger for the H (voiceless) category than for the L (voiced) one for all Eastern speakers. The average duration of a voiceless stop is more than twice as great as that of a voiced stop. The effect is not significant for the Northern ($p = 0{\cdot}127$) or Western dialect ($p = 0{\cdot}344$). The durations of the originally voiceless consonants for Speakers N1 and N2 are somewhat greater than the originally voiced ones, but they are all audibly voiceless, and the duration difference is very small compared to the difference for Eastern speakers. Since they have an aspiration contrast, the result is difficult to interpret for the Western speakers.

3.5.3 *Aspiration.* The results are shown in Table IV, which shows that the factor Tone has a significant effect ($p = 0{\cdot}036$) on aspiration in the Western dialect. The difference in VOT between the L and H categories

(a)	factor/ interaction	df_1	df_2	F	p
Western Kammu	Tone	1	2	26·3	0·036*
	Cons	1	2	9·5	0·091
	Tone × Cons	1	2	0·0	0·990
	Tone × Cons × Speaker	2	60	1·0	0·369

(b)	H	L
W1	8	22
W2	11	18
W3	9	23
N1	20	18

Table IV

Voice onset time: (a) analysis of variance for the Western speakers; (b) mean VOT (ms) for the H and L categories for the Western speakers and for Speaker N1.

is, on the average, 14 ms for W1 and W3. Speaker W2 has a smaller VOT difference (7 ms), and her VOT varies more. We might speculate that this speaker tries to suppress aspiration, a characteristic feature of the Western dialect, which has low status among speakers of other Kammu dialects.

VOT was also measured for Speaker N1, whose recordings were used in the perception study. An analysis of variance performed on his VOT showed no significant effect of Tone ($F(1,20) = 0{\cdot}6$, $p = 0{\cdot}44$), and the average VOT differs only by 2 ms for the H and L categories.

3.5.4 *Microprosody*. Tests and mean values of the initial fall are presented in Table V. As expected, the results show that the factor Tone has a significant effect ($p = 0{\cdot}034$) on the initial fall in the Eastern dialect, which has not undergone tonogenesis, but no significant effect in the Northern ($p = 0{\cdot}107$) or Western ($p = 0{\cdot}972$) dialect. All Eastern speakers except E5 have a greater fall for the H (voiceless initial) than for the L (voiced) category.

3.6 Discussion

The results show that Eastern Kammu speakers generally make no consistent F0 differences in the minimal pairs given in (2), while, as expected, the Northern and Western Kammu speakers in this study generally make a clear F0 difference between the high and low tones (cf. Gårding & Lindell 1977 for Northern Kammu).

Thus, from the production point of view, Eastern Kammu is a non-tonal language which does not even use F0 to sharpen the contrast between words beginning with voiceless and voiced consonants (apart from microprosodic effects). Northern Kammu has lost the voicing contrast in stops and sonorants and relies only on fundamental frequency to distinguish words which differ in consonant voicing in Eastern Kammu. Western Kammu uses a combination of tone and consonant differences in these words.

(a)	factor/ interaction	df_1	df_2	F	p
Eastern Kammu	Tone	1	5	8·4	0·034*
	Cons	2	10	3·2	0·086
	Tone × Cons	2	10	2·0	0·187
	Tone × Cons × Speaker	10	180	1·7	0·083
Northern Kammu	Tone	1	3	5·2	0·107
	Cons	2	6	3·2	0·112
	Tone × Cons	2	6	1·0	0·426
	Tone × Cons × Speaker	6	120	1·9	0·092
Western Kammu	Tone	1	2	0·0	0·972
	Cons	2	4	2·7	0·181
	Tone × Cons	2	4	2·8	0·172
	Tone × Cons × Speaker	4	90	3·1	0·019*

(b)

	H	L
E1	7·2	4·3
E2	6·1	2·0
E3	7·2	3·7
E4	13·2	8·7
E5	6·5	8·5
E7	9·9	5·5

	H	L
N1	2·8	4·6
N2	−0·2	3·8
N3	5·3	7·0
N4	5·3	5·3

	H	L
W1	0·0	−1·5
W2	−2·2	−0·5
W3	4·2	4·0

Table V

Initial fall: (a) analysis of variance; (b) mean initial fall (Hz) for the H and L categories for all speakers. Negative values represent initial pitch rises.

4 Perception study

4.1 Material and procedure

The test material was based on two of the sentences which were used in the production measurements: /kìi mə̀h kláaŋ nám/ ‘This is a big eagle’, and /kìi mə̀h klàaŋ nám/ ‘This is a big stone’. These two sentences were recorded in Lund by Damrong Tayanin, a speaker of the Northern dialect (Speaker N1). The difference in F0 between the tone-bearing [aː] vowel in the two versions was 30 Hz, with the low tone at 100 Hz and the high tone at 130 Hz. Using PSOLA resynthesis techniques (Moulines & Charpentier 1990, Möhler & Dogil 1995), five synthesised versions of both sentences were prepared by stylising the F0 contours with straight lines, as shown in Fig. 4. Thus a total of ten synthesised stimuli were prepared, comprising two versions of each of the five following F0 values for the

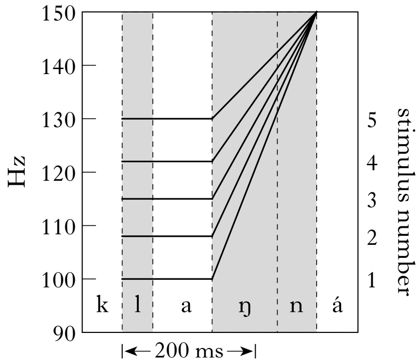

Figure 4
Stimuli for the perception test.

tone-bearing vowel: 100 Hz, 108 Hz, 115 Hz, 122 Hz and 130 Hz. Three repetitions of each of the ten stimuli were presented in random order to the test subjects. The test was performed immediately after the recording sessions described above. An answer sheet displaying a picture of a stone and an eagle was used so the subjects could indicate which word they heard.

4.2 Subjects

With the exception of speakers N1 and E1, the test subjects for the perception test were the same as the speakers for the production study. Since the test stimuli were made by manipulating recordings of speaker N1 (Damrong Tayanin) and he was aware of the purpose of the experiment, he was not included in the perception test. Speaker E1 did not wish to participate in the perception test.

4.3 Binomial tests for different cues

An exact binomial test was designed in order to find out which cues, ‘fundamental frequency’ (the five pitch levels in the stimuli), ‘initial consonant’ (which was [k] for all stimuli) or ‘original recording’ (i.e. if a stimulus was synthesised from the original recording of ‘eagle’ or of ‘stone’), were used by the subjects for discriminating between the target words ‘eagle’ or ‘stone’. We expected that the Eastern dialect listeners would use ‘initial consonant’ as their main cue, and that Northern and Western dialect listeners would use ‘fundamental frequency’. We expected that none of the listeners would use ‘original recording’ as their main cue, although we did not want to exclude the possibility that the stimuli retained some feature of the recording from

	E2		E3		E4		E5		E6		E7	
	L	H	L	H	L	H	L	H	L	H	L	H
5	3	2	3	3	3	3	2	1	3	3	3	3
4	3	3	3	3	3	3	1	3	3	3	3	3
3	3	3	3	2	3	3	1	1	3	3	3	3
2	3	3	2	3	3	3	1	2	3	3	3	3
1	3	2	1	3	3	3	0	0	3	3	3	3

	N2		N3		N4		W1		W2		W3	
	L	H	L	H	L	H	L	H	L	H	L	H
5	3	3	1	3	3	3	2	3	3	2	0	1
4	3	3	1	2	3	2	1	3	2	2	1	3
3	0	0	2	1	1	0	0	2	3	3	1	0
2	0	0	1	1	0	0	0	2	3	2	2	1
1	0	0	2	2	0	0	0	2	3	3	1	0

Table VI

Results of the perception tests. For each subject, the number of 'eagle' answers for each stimulus is shown. L and H indicate whether the original recording from which the stimulus was synthesised had low ('stone') or high ('eagle') tone, and the numbers 1–5 in the left margin denote F0 height (see Fig. 4).

which it was synthesised that could be perceived and used as a cue by the listeners.

For each speaker, the number of answers compatible with each cue was counted, and this number was used as a statistic for testing the hypothesis that the subject used the given cue against the null hypothesis that the speaker used a random strategy. Under the null hypothesis, this statistic is binomially distributed with the probability parameter 0·5, so the p-value for this test is equal to the probability that a binomially distributed random variable with the probability parameter 0·5 is greater than or equal to the test quantity.

For example, assuming that a speaker uses 'initial consonant' as the cue, the compatible answer is 'eagle' for all stimuli, because all stimuli have a voiceless initial [k]. Since subject E2 answered 'eagle' in 28 cases of 30 possible (see Table VI), the p-value is the probability that a binomially distributed random variable with the parameters (30, 0·5) is greater than or equal to 28, i.e. $p < 0{\cdot}001$. This test result can be interpreted as showing that E2 uses 'initial consonant' as a cue, tested at this level of significance.

For F0 as the cue, answering 'eagle' for the two highest F0 levels (4, 5) and 'stone' for the two lowest ones (1, 2) was counted as compatible with

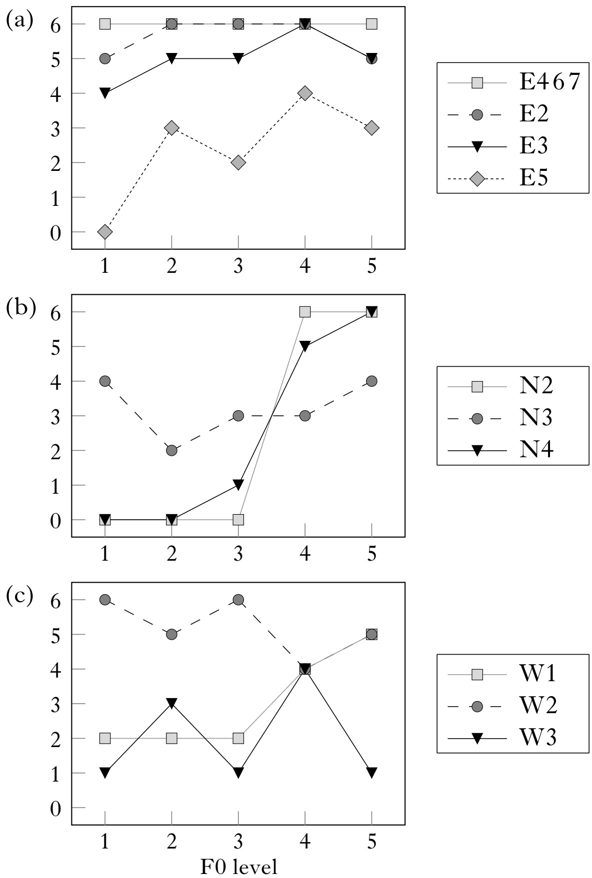

Figure 5
Results of the perception tests: (a) Eastern Kammu listeners; (b) Northern Kammu listeners; (c) Western Kammu listeners. For each subject, the number of 'eagle' answers are plotted against the F0 level of the stimulus (see Fig. 4).

the cue, and the answers to stimuli with pitch level 3 were disregarded. In this case, the parameters of the binomial distribution are (24, 0·5). Again using E2 as an example, he gave 11 'eagle' answers on levels 4 and 5, and 1 'stone' answer on levels 1 and 2, so he gave 12 compatible answers out of 24, suggesting that he does not use F0 as a cue. This is confirmed by the test, whose p-value is 0·581.

4.4 Results

The results of the perception tests are shown in Table VI for each subject and each stimulus, and in Fig. 5 the number of 'eagle' answers are plotted

	fundamental frequency		initial consonant		original recording	
		p		p		p
E2	12/24	0·581	28/30	< 0·001*	13/30	0·819
E3	15/24	0·154	26/30	< 0·001*	17/30	0·292
E4	12/24	0·581	30/30	< 0·001*	15/30	0·572
E5	16/24	0·076	12/30	0·900	17/30	0·292
E6	12/24	0·581	30/30	< 0·001*	15/30	0·572
E7	12/24	0·581	30/30	< 0·001*	15/30	0·572
N2	24/24	< 0·001*	12/30	0·900	15/30	0·572
N3	13/24	0·419	16/30	0·428	17/30	0·292
N4	23/24	< 0·001*	12/30	0·900	13/30	0·819
W1	17/24	0·032*	15/30	0.572	24/30	< 0·001*
W2	10/24	0·846	26/30	< 0·001*	13/30	0·819
W3	13/24	0·419	10/30	0·979	15/30	0.572

Table VII

Binomial tests for different cues in the perception experiment. The table shows the number of answers compatible with each of the three different assumptions that the listener used the cue 'fundamental frequency', 'initial consonant' or 'original recording' to differentiate the test words 'eagle' and 'stone', and the p-values.

against the F0 level of the stimulus. The results of the binomial tests are shown in Table VII.

Five of the six Eastern (non-tonal) Kammu listeners heard the word 'eagle' in the great majority of cases, regardless of whether the original was /kláaŋ/ 'eagle' or /klàaŋ/ 'stone', and regardless of F0. The binomial test showed significance levels less than 0·001 for 'initial consonant', and no significance for the two other cues, indicating that these speakers used segmental information as their only cue. The sixth speaker (E5) seems to have guessed at random.

Two of the three Northern Kammu listeners consistently used F0 to distinguish between the words ($p < 0{\cdot}001$; cf. also Fig. 5), regardless of the original recording; here as well, the remaining listener (N3) seems to have resorted to random guessing. This result is similar to that found by Gandour *et al.* (1978). As expected, the binomial test showed that none of the Northern Kammu speakers used the cue 'initial consonant', and none of the speakers used the cue 'original recording'.

The results of the Western Kammu speakers are more difficult to interpret. Listener W2 uses only the segmental information ($p < 0{\cdot}001$), apparently identifying the initial [k] of the test words with Western Kammu unaspirated [k] in /kláaŋ/ 'eagle' rather than with aspirated [k^h] in /k^hlàaŋ/ 'stone'. She does not use F0 or the original recording as cues. Speaker W1 is the only subject who uses the original recording as a cue

($p < 0{\cdot}001$), but he relies on F0 as well ($p = 0{\cdot}032$). Here as well, one listener (W3) seems to have guessed at random.

4.5 Discussion

The results of the perception test showed that speakers of Eastern Kammu did not distinguish between the minimal pairs which differed only in tone. On the other hand, two of the three speakers of Northern Kammu were extremely sensitive to small differences in fundamental frequency, and were able to use these differences to categorise the stimuli. The speakers of Western Kammu showed individual variation. One subject (W1) demonstrated sensitivity to fundamental frequency differences as well as to features of the original recordings. The other two Western Kammu speakers did not use the tonal differences to make the category distinctions. It is possible that Speaker W1, who makes a consistent difference between the initial stops (unaspirated *vs*. aspirated) could detect the small difference between these consonants in the speech of Speaker N1 (see §3.5.2), whose recordings were the base for the perception material. As seen in §3.5.3, Speaker N1 has no aspiration contrast, so aspiration could not be the cue. The lack of consistency in the responses by the Western Kammu subjects could be a reflection of the fact that Western Kammu combines tone and consonant differences in the test words, thus the different individuals may have used different strategies during the listening test.

5 General discussion

From a tone-language perspective, Northern Kammu represents a language where differences between the tones are small in absolute terms (generally less than 25 Hz in production). Similarly small differences have been documented for other languages with only two tones (Maddieson 1978), and also for the level tones in languages with more complex tonal systems, notably the mid and low tones of Thai (Abramson 1962, Gandour *et al*. 1991). It seems remarkable that languages such as Northern Kammu maintain such a small contrast. A greater contrast would facilitate perception and hinder possible tonal confusions along the lines of maximal contrast proposed for vowel systems by Liljencrants & Lindblom (1972). On the other hand, an acoustically small but perceptually salient tonal contrast is consistent with an interpretation involving an economy of speech gestures where phonetic space is underexploited (Lindblom 1983).

One possible explanation in the Kammu case is that the tonal system of Northern Kammu has perhaps remained relatively unchanged since tone was acquired and may represent an early stage in tonal development. We can speculate that consonant-voicing differences have been replaced by F0 differences as the main acoustic cue by shifting the focus of perception from features of the onset consonant such as VOT to features of the vowel, mainly F0. Although the consonant-induced F0 perturbations at the beginning of the vowel are large enough to be perceived, they must probably be extended to the entire vowel, or at least to the spectrally stable middle part of the vowel, before they can replace consonant voicing as the perceptually relevant cue (cf. House 1990, 1999).

From a tonogenesis perspective, the production results from Eastern Kammu give rise to a number of questions. On the one hand, this investigation shows that there is a clear-cut distinction between Northern Kammu, which under a traditional analysis is a tone language, and Eastern Kammu, which is a completely non-tonal language. Words which differ only in the tones in Northern Kammu differ only in the consonants in Eastern Kammu, and speakers of Eastern Kammu do not produce or perceive those features which are characteristic of the Northern dialect. From this point of view, the two dialects are not intermediate stages between tonal and non-tonal languages, in spite of the fact that speakers of them can communicate without difficulty, and are more aware of lexical than of phonological differences between the dialects.

On the other hand, Kammu is clearly participating in a tonogenetic process, which can be seen as part of the tone split that has taken place (and is still taking place) in the entire mainland Southeast Asian linguistic area (see e.g. Matisoff 1973, Svantesson 2001), involving languages such as Chinese, Thai and Vietnamese, to mention a few well-known examples. If Eastern Kammu were currently in the process of acquiring tones, we would expect to find F0 differences between H and L categories throughout the vowel. This was not the case. We did, however, find small differences between the H (voiceless) and L (voiced) categories during the first 50 ms of the vowel, where the H categories demonstrated a greater F0 fall than did the L categories (see §3.5.4). While this difference is consistent with the assumption that tonogenesis of the type found in Kammu is based on microprosodic effects of the initial consonants on the vowel onsets (Hombert *et al.* 1979, Löfqvist *et al.* 1989), the effects found in our data are very small. We can think of two explanations for this. One is that Eastern Kammu speakers mark their identity as non-tonal speakers differing from speakers of surrounding tonal languages (e.g. Lao and tonal Kammu dialects) by minimising the tonal differences between vowels following voiced and voiceless consonants. The other explanation is that the effect of microprosody is not the only mechanism responsible for tonogenesis of this type. It may not be impossible that similar perceptual mechanisms involving other features such as VOT or voicing can give rise to the percept of a tonal distinction. In this sense, the speakers of Eastern Kammu have not dissociated these features from the consonant.

6 Is tonal Kammu a tone language?

Ohala (1993) offers a listener-oriented, perceptual explanation for sound change whereby listeners perform a ‘dissociation’ parsing error and fail to associate two related events in the speech signal. Thus, if F0 is lower following a voiced consonant than following an unvoiced consonant, a dissociation of F0 from the consonant will give rise to a tonal distinction. In the case of Northern Kammu, however, one interpretation can be that the dissociation has not yet occurred. In this sense, the tonal differences of Northern Kammu can be regarded as primarily segmental features still coupled to the voiceless–voiced dichotomy of the initial consonant, although they are realised on the syllable rhyme. Several facts support this interpretation:

(i) The distribution of tones: some initial consonants, including the voiceless fricatives /h/ and /s/ and the aspirated stops, occur only with high tone (e.g. /hóoc/ 'to finish', /séʔ/ 'louse'). These consonants have no voiced counterparts in Eastern Kammu. An initial glottal stop occurs only with low tone (e.g. /ʔòm/ 'water'). See Svantesson (1983a) for further discussion.

(ii) There are morphophonological tone changes that can be explained only by assuming that the initial consonant determines the tone in Northern Kammu. One example is causatives derived with the prefix /p-/, which have high tone regardless of the tone of the base (/háan/ 'to die', causative /pháan/; /rə̀h/ 'to rise', causative /prə́h/). Obviously, the high tone originates in the prefixed consonant in cases such as this (see Svantesson 1983a for further details). Another example is provided by infixes which create 'sesquisyllabic' words consisting of an unstressed 'minor' syllable with an epenthetic schwa vowel as nucleus, and a stressed 'major' syllable, a type of word that is common in many Mon-Khmer languages (cf. Svantesson & Karlsson 2004). One example is the nominaliser /-mn-/: /kóh/ 'to cut' > /km̀.nòh/ 'cut-up salt' *vs.* /kòh/ 'to weed' > /km̀.nòh/ 'weeding period'. In such words, the tone of the base transfers to the minor syllable (/km/ in this example), and is thus determined by the initial consonant, the only segment shared by the base and the minor syllable of the derived word. The tone of the major syllable (/noh/) is low in both cases, determined by the initial voiced sonorant /n/ of this syllable.

(iii) In traditional Kammu word-play, the words are transformed as illustrated by the following: /kláaŋ/ becomes /klɔ́-kláaŋ-klʌ́ʌn/; /klàaŋ/ becomes /klɔ̀-klàaŋ-klʌ̀ʌn/. Thus the word is preceded and followed by syllables consisting of the original onset and the rhyme /ɔ/ and /ʌʌn/ respectively. The tone is not changed, and is thus treated as belonging to the onset.

(iv) Unlike the case in traditional Chinese poetry, for example, the tones play no role in traditional Northern Kammu poetry, where words rhyme if they have the same segments in the syllable rhyme, so that e.g. /múuc/ 'ant' rhymes with /pùuc/ 'wine' (see Lundström 2006).

Facts such as these show that the tones of Northern Kammu belong phonologically to the syllable onset, as features of the syllable-initial consonant. Thus Northern and Eastern Kammu have the same phonological representations for cognate words, the only difference being the purely phonetic property that this feature is realised phonetically as high *vs*. low tone in Northern Kammu, but as absence *vs*. presence of voicing in the initial consonant in Eastern Kammu.

The situation in Kammu is paradoxical, then. On the one hand, a classical phoneme analysis will give the impression that Northern Kammu is very different from Eastern Kammu. Northern Kammu is a typical tone language in the sense that F0 differences serve to distinguish otherwise identical words, as was shown above both for production and perception, but Eastern Kammu is not a tone language; its speakers neither produce nor perceive these F0 differences. Furthermore, the segmental phoneme inventories of these two languages differ drastically, Eastern Kammu having twelve more consonant phonemes than Northern Kammu (four voiced stops and eight voiceless sonorants). On the other hand, speakers of Northern Kammu understand Eastern Kammu without difficulty (and *vice versa*), and the speakers are much more aware of lexical than of phonetic differences.

Our analysis of Northern Kammu as phonologically identical to the non-tonal language Eastern Kammu resolves this paradox: Northern Kammu should not be regarded as a tone language on the level of phonological representation, although fundamental frequency is used as a contrastive property on the phonetic level.

7 Conclusion

Eastern Kammu does not have lexical tones, while Northern Kammu does use fundamental frequency to distinguish words. On the level of phonological representation these languages are identical, however, the Northern Kammu tones belonging to the initial consonant. On the level of phonetic production, this corresponds to the fact that the Northern Kammu tone system is maximally simple, having two level tones, which, furthermore, are acoustically very close to each other. One gets the impression that Northern Kammu makes the presence of tones as inconspicuous as possible, signalling the basic identity of Northern and Eastern Kammu and emphasising the fact that tonogenesis is an ongoing process in this language.

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