Pitch-phonation correlations in Sgaw Karen•

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1 Introduction

This paper continues a line of research was initiated by the late Katrina Hayward, the first and principal author in 1998 of Hayward, *et al.* (to appear), which examined voice quality-pitch associations in Yorùbá. In that paper, we found evidence to suggest that voice quality, of which phonation type was one component, contributed to the phonetic character of the low tone in Yorùbá. Part of our conclusion was that, at least for Yorùbá, voice quality may help to distinguish between two tones in one register (low and mid) rather than emphasising the difference between registers. This finding was juxtaposed with the possibility that characteristic voice quality of the Yorùbá low tone was merely an artefact of its position near the bottom of the pitch range.

The main conclusion, however, was that much more research needs to be done on the relationship between voice quality and fundamental frequency, since the associations are not universal, despite the fact that distinctive voice qualities are reportedly associated with specific tones in many tone languages. The present paper is a step towards this end, and adopts a similar experimental approach.

1.1 Tone and syllable type

(Jones 1986) takes the view that the term 'tonal' has been 'rendered virtually meaningless' through being applied to virtually any language in which pitch is in some way lexically or morphologically distinctive. This suggestion was made within the context of South East Asian languages, but becomes doubly resonant in a broader forum including also East Asian and African languages, where one may encounters a bewildering diversity of contrastive pitch systems.

One may define a 'conventional' tone language as one in which any given syllable in any given context may be identified from its pitch or pitch contour as bearing one of a closed set of tones. Vietnamese may be such a language: it is cited by (Đở Thế Dũng *et al.* 1998:398) as an example of a tone language in which tone *sandhi* phenomena are not observed (though coarticulatory effects may be observed in strings of adjacent tones). Properties typically encountered in the tone systems of African languages which elaborate on this basic type are so-called downstep and tone terracing (see Laver 1994:470 ff.), while those familiar with Asian languages will

• The author acknowledges the support of grants from the British Academy and the School of Oriental and African Studies which supported attendance at the *VIth International Conference on the Languages of the Far East, South East Asia and West Africa*, held during September 2001 at the University of St Petersburg, where an earlier version of this paper was presented. Thanks are due to Bernard Howard for assistance with recording and to Paul Boersma for help with writing scripts for the Praat phonetics program.

Special thanks are to Katrina Hayward, whose crystal clear thinking forms part of the basis for this work. I dedicate this paper to her memory.

recognise tone sandhi as a common feature of tone systems in that region (Chen 2000). In such languages, the correct identity of a tone may be recovered only by interpreting the pitch of the tone through the filter of the sandhi or other phonological rules of the tone system.

There are also languages in which pitch is one component within a complex of phonetic features which make up contrasts which otherwise appear to pattern in the same way as tone. (Jones 1986):135 calls these systems "pitch register" systems, in which pitch is "minimally contrastive only between syllables of like type". The rationale for this is that in such languages the pitch element of the lexical pitch contrasts is so variable that it only makes sense to refer to pitch when comparing two syllables in actual juxtaposition if they have otherwise similar syllable structures.

2 Phonation type, voice quality and pitch in Sgaw Karen

Sgaw Karen is a Tibeto-Burman language spoken by about two million people, concentrated mainly in the Karen State of Burma and across the border into western Thailand, but also scattered across the predominantly Burmese-speaking delta region of Burma. In Karen orthography, there are six possible tonal contrasts, shown in Table 1.

Table 1 Karen names of Karen tones.

usual alphabetical order of tone	Karen orthography	name of tone in Karen	romanisation
1	—	tg	a^{1}
2	—>	tXo	er^{1}thi^{1}
3	—m	tmo	a^{3}thi^{1}
4	—;	zsX.q	hpler^{5}hsi^{1}
5	—.	[;o	ha^{4}thi^{1}
6	—R	u.z	ke^{5}hpo^{1}

Table 2 sets out various phonetic descriptions of Karen tones in some of the published sources. It is immediately apparent that there are serious contradictions, especially with respect to the descriptions of pitch characteristics.

(Haudricourt 1975) surveys the mechanisms by which various tone systems have developed in a range of East and South East Asian languages, including a brief mention of Sgaw Karen, using secondary data taken from the Linguistic Survey of India (Grierson 1903). This source suggests that Sgaw Karen is "an example of a language whose tonal system has passed from two phonemic tones to four." Haudricourt (1942) showed that the six tones of Sgaw (and Pwo) Karen resulted from the doubling of a three-tone system, but that one of these three tones was derived from syllables with final stops, so that only two proto-tones needed to be reconstructed. Haudricourt (1975:339) revises this position in light of the work of Luce (1957); Jones (1961) and Burling (1969) to posit the reconstruction of three Karen tones, rather than two.

Table 2 Summary of existing descriptions of Karen tones.

tone	Karen script	Description in Gilmore (1898)	Descriptions cited in Taylor (1927:95)	Transcription and description (Chao tone letters) from Jones (1961:64)	
1	—	with a rising inflection	high, level and long	ˊ	55
2	—›	heavy falling inflection	begins at middle register and falls considerably; about medium length	ˋ	21
3	—ၢ	abruptly, at a low pitch	very slightly above middle register, level and short; sometimes abrupt; pitch lower than 1and 4 but same as 6	ˋʔ	11ʔ
4	—;	abruptly, at an ordinary pitch	high, level and abrupt, ... has a glottal check	ʔ	33ʔ
5	—.	with a falling circumflex inflection	begins high, falls steadily to middle register, long	ˊʔ	53ʔ
6	—ၤ	with a prolonged even tone	same pitch as 3, slightly high, level, and long		33

Jones (1961) is a descriptive and comparative monograph focussing on six dialects of Karen, including two of Sgaw Karen. The dialect which corresponds most closely to the speech of the language consultant used for the present paper is referred to by Jones as Moulmein Sgaw. In Jones's (1961) analysis, Moulmein Sgaw has three tones, each of which occurs in two allophones, with and without final [ʔ]; he revised this analysis in the light of his proposal of 'pitch register' languages to one with two 'pitch registers in each of which plain, breathy and stopped syllables occur' (Jones 1986:137). We shall see that this analysis is motivated more by phonological design than by phonetic reality.

2.1 Experimental procedure

Whether or not one adopts Jones's term, 'pitch register' systems are difficult to study and describe: if they are approached as conventional tone languages, the tones suddenly appear elusive as the pitches shift and bend around, influenced by phonological, morphological, syntactic or intonational contexts. The analyst can choose to try to account for and describe pitch phenomena for as many contexts as possible, in which case problems of data reduction dictate that detail in one will be at the expense of comprehensiveness in the other. Alternatively, one can opt to control the context as much as possible, allowing for more detailed description of the pitch phenomena, but running the risk that the frozen snapshot image of the pitch system does much resemble its real-life counterpart. One encouraging improvement in these bleak circumstances is the rapid expansion of the capacity to process large quantities of data quickly by computer.

Here, I have chosen to collect detailed phonetic data for Karen tonal contrasts in controlled-context suspended animation, as I have done elsewhere for Burmese (Watkins 2000).

The design of this experiment was constrained by the availability of a single Karen-speaking consultant. The word list consisted of three quasi-randomised sets of nonsense CV syllables, each containing three repetitions an /a/ vowel in each of the six orthographic Karen tones. Two of the sets of syllables began with an initial /m/ and the third began with an initial /k/. This yielded a total of 54 tokens. The syllables were placed in the frame sentence:

> ew ____ 'tR
> /nətɛ^{1} ____ di^{4}ʔi^{6}/
> "You say ___ like this."

The consultant recorded for this study was a female speaker of Sgaw Karen aged 29, who did not report abnormal speech or hearing. She was brought up in Kyaukkyi (ကျောက်ကြီး) and spent her teenage years in Kawmuya (ကော်မှူးရား) and Htihta (ထီးထာ). Though bi-dialectal in Karen, for the purposes of this study she read in a variety of Karen widely recognised as the standard, though the possibility of interference from her other dialect cannot be ruled out, as we shall see later. The materials were presented to the consultant in written form.

Simultaneous digital audio and laryngograph recordings were made on minidisk in a sound-proofed booth in the recording studio of the School of Oriental and African Studies using the following: a Bruel and Kjær condenser microphone (type 4165); a Bruel and Kjær measuring amplifier (type 2609); a Fourcin portable laryngograph and processor (Laryngograph Ltd.). (For general information about the laryngograph and its use, see Abberton *et al.* (1989) and Howard *et al.* (1990). The laryngograph and audio recordings were converted to computer sound files using the Goldwave digital audio editor, version 4 (*www.goldwave.com*), with the sampling rate set at 11025 Hz. The remaining analysis was carried using the Praat program, version 3.9.28 (*www.praat.org*).

2.2 Measurements

The vowels in the syllables of interest were segmented by hand using speech pressure waveforms and spectrograms, at which point the presence or absence of final glottal stops could be determined. Computer scripts were written ad hoc to direct the Praat program shell to make several series of measurements, using where possible the software's built-in capacity to do so automatically.

Fundamental frequency and closed quotient were derived from the laryngograph trace. Closed quotient (CQ) is defined as the ratio of the duration of the closed phase to the duration of one whole period of vocal fold vibration. In the algorithm in the script which was written to calculate this from the laryngograph waveform, the point of vocal fold closure – the beginning of the closed phase – was defined as the positive peak of the differentiated waveform, while the end of the closed phase was a threshold fixed at 30% of the total peak-to-peak amplitude of the waveform period in question. Other things being equal, higher CQ is diagnostic of relatively creakier phonation while lower CQ is diagnostic of relatively breathier phonation. In measurements of syllables in Wa (Watkins 1999), CQ contours were found to be a very clear indicator of glottal consonants: rising CQ is associated with glottal stops /ʔ/ while falling CQ is indicative of breathy-voiced /ɦ/.

The duration of each vowel was measured from the speech pressure waveform and derived spectrograms. If a final glottal stop was present, then the duration included the glottal stop.

The frequencies of the first three formants were measured at the mid-point of each vowel. There are many languages in which some kind of register or phonation type contrast interacts with vowel quality in some way, either in the form of a synchronic phonological contrast or diachronically, by splitting or doubling vowel systems (see Diffloth 1980:37 on Wa and Khmer).

The measurements of intensity were calculated automatically by the Praat program. Spectral tilt was measured using a variant of the ‘resonance balance’ measure described by Schutte and Miller (1985). The Praat program was instructed to resample the sound at 10 kHz and calculate the difference in energy present in two frequency bands (0-1 kHz and 3.5 – 4.5 kHz) of narrow-band spectra (40 Hz effective bandwidth). Higher values of this measure, indicating a greater difference in energy in the two frequency bands, indicate steeper spectral tilt and relatively more energy concentrated in the low frequency band, a characteristic of breathy voice, while lower values of this measure may indicate less spectral tilt, with relatively more energy concentrated in the 3.5 – 4.5 kHz frequency band. While measuring spectral tilt can yield an index of relative creakiness or breathiness of phonation type (Ní Chasaide and Gobl 1997:439), spectral tilt may also be reduced by other factors such as vocal effort and loudness, and measuring phonation type in this way is not straightforward (Watkins 1997).

Naturally, the configuration of the supraglottal vocal tract also influences the spectral profile, but since all the speech material for this investigation was taken from similar vowels, this unwanted effect is reduced to a minimum.

F0, CQ, intensity and spectral tilt were all measured at three points evenly spaced through the vowel, after one quarter, one half and three-quarters of the vowel’s measured duration.

To sum up, the measurements taken from each vowel were:

- presence or absence of final glottal stop determined
- fundamental frequency (3 measurements)
- closed quotient (3 measurements)
- duration
- frequencies of F1, F2 and F3 (at midpoint of vowel only)
- intensity (3 measurements)
- spectral tilt (3 measurements)

Statistical analysis was carried out using the SPSS Statistics package (version 10.0). Means and standard deviations for all the measures were computed for each tone. A two-way ANOVA was carried out for each measure, with tone and syllable set as the independent variables. A one way ANOVA, with Scheffé post-hoc comparisons was also carried out for each measure, with tone as the single factor. In the presentation and discussion of statistical data, the significance or non-significance of a result is determined by setting the critical threshold at $p=0.05$.

2.3 Results

With a broad set of measurements such as there, the results are complex. The results of each measure are discussed individually below, after which the overall findings are discussed.

2.3.1 Summary of numerical data

Table 3 Means (n=9) and standard deviations of all measurements made of each Karen tone.

		Tone 1		Tone 2		Tone 3		Tone 4		Tone 5		Tone 6		Total	
		mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
f0 (Hz)	onset	241.046	6.48	195.27	9.09	186.54	7.80	239.83	12.24	193.91	10.62	217.85	3.46	212.41	23.73
	mid	240.5459	6.04	180.50	6.29	175.51	6.38	221.61	16.19	180.20	9.35	213.89	4.43	202.04	26.33
	end	229.8404	5.52	161.16	26.58	163.07	33.89	198.19	43.71	150.94	47.89	205.33	5.24	184.76	41.71
CQ (%)	onset	40.7125	6.55	46.49	7.43	55.93	6.66	41.80	5.23	46.07	6.95	35.17	10.84	44.04	9.34
	mid	39.39829	6.24	48.70	7.22	54.67	5.34	46.71	3.44	50.52	7.11	35.80	10.74	46.11	9.24
	end	40.95503	6.17	49.97	10.35	49.67	6.11	58.05	5.24	52.57	5.35	39.73	6.97	47.84	9.28
duration (s)		0.340	0.027	0.301	0.050	0.324	0.063	0.171	0.015	0.272	0.050	0.332	0.048	0.290	0.072
F1 (Hz)		990.32	99.23	949.36	88.89	944.56	101.87	1164.51	91.41	986.33	88.26	861.16	71.84	982.70	126.61
F2 (Hz)		1407.53	135.69	1547.82	106.41	1497.88	67.21	1686.18	104.17	1539.61	153.93	1562.24	71.13	1540.21	134.73
F3 (Hz)		2488.91	429.73	2371.19	445.15	2286.26	463.46	2618.12	324.80	2427.75	511.55	2877.53	255.73	2511.63	439.79
intensity (rel dB)	onset	80.78	1.84	79.82	2.38	79.79	3.53	84.66	2.17	80.25	2.73	78.81	2.96	80.68	3.16
	mid	80.46	2.05	74.60	2.87	77.61	2.76	84.69	1.41	77.46	2.55	79.22	3.13	79.01	3.96
	end	79.41	2.30	69.91	5.33	75.64	3.10	81.17	1.23	74.28	5.47	77.95	3.26	76.39	5.17
spectral tilt (rel dB)	onset	-26.10	4.43	-28.33	5.57	-27.83	4.07	-21.65	5.75	-27.16	4.02	-25.64	3.70	-26.12	4.96
	mid	-27.24	4.00	-26.63	4.14	-28.07	4.20	-17.95	6.67	-23.86	3.31	-26.42	3.52	-25.03	5.46
	end	-26.63	2.71	-24.46	4.44	-27.27	4.49	-16.56	4.36	-20.49	3.10	-29.43	4.26	-24.14	5.81

2.3.2 Statistical analysis of data

ANOVA test results

Table 4 Results of ANOVA tests performed with SPSS software on each of the measured correlates of tone with respect to the independent variables: 6 tones, 3 syllable sets. The tests were performed on 54 tokens. Significant results ($p < .05$) are marked with an asterisk. Values of p less than 0.0005 are recorded as 'near 0'.

		Main effects				2-way	
		TONE (d.f. = 5)		SYLLABLE SET (d.f. = 2)		TONE X SYLL. SET (d.f. = 9)	
		F	p	F	p	F	p
fundamental frequency	onset	93.79	near 0 *	8.71	0.001 *	2.75	0.021 *
	mid	140.33	near 0 *	13.14	near 0 *	4.34	0.002 *
	end	4.56	0.004 *	0.37	0.696	0.34	0.954
closed quotient	onset	11.09	near 0 *	3.12	0.061	3.50	0.006 *
	mid	11.56	near 0 *	0.32	0.731	3.62	0.005 *
	end	12.69	near 0 *	3.06	0.064	2.82	0.018
duration		12.49	near 0 *	4.93	0.015 *	0.68	0.718
F1		10.64	near 0 *	9.63	0.001 *	0.23	0.987
F2		7.84	near 0 *	17.00	near 0 *	0.49	0.865
F3		2.94	0.031 *	10.67	near 0 *	1.63	0.158
intensity	onset	3.81	0.010 *	3.97	0.031 *	0.96	0.493
	mid	11.51	near 0 *	1.77	0.190	1.21	0.330
	end	7.93	near 0 *	1.53	0.236	0.78	0.636
spectral tilt	onset	4.97	0.003 *	3.68	0.039 *	1.60	0.169
	mid	5.51	0.001 *	2.40	0.110	0.55	0.825
	end	8.31	near 0 *	1.25	0.303	0.46	0.890

Results of Scheffé post-hoc comparison

Table 5 Results of post-hoc Scheffé comparisons applied to each measure, calculated from one-way ANOVA tests carried out on each with tone as the single factor. As with the other statistical tests, the critical value of p is taken as 0.05.

dependent variable		homogeneous subsets by tone
fundamental frequency (Hz)	onset	(1, 4) > (6) > (2,5,3)
	mid	(1) > (4,6) > (2,5,3)
	end	(1,6,4) > (6,4,3,2) > (4,3,2,5)
closed quotient (%)	onset	(3,2,5) > (2,5,4,1,6)
	mid	(3,5,2,4) > (5,2,4,1) > (4,1,6)
	end	(4,5,2,3) > (5,2,3,1,6)
duration (s)		(1,6,3,2,5) > (4)
F1 (Hz)		(4) > (1,5,2,3,6)
F2 (Hz)		(4,6,2,5) > (6,2,5,3,1)
F3 (Hz)		none
intensity (rel dB)	onset	(4,1) > (1,5,2,3,6)
	mid	(4) > (1,6,3,5) > (3,5,2)
	end	(4,1,6,3) >(1,6,3,5) > (3,5,2)
spectral tilt (rel dB)	onset	none
	mid	(3,1,2,6,5) > (5,4)
	end	(6,3,1,2) > (1,2,5) > (5,4)

2.3.3 Final glottal stops

Glottal stops could be consistently be identified in the spectrograms of Tones 3 and 4, and were consistently absent from Tones 1 and 6, as illustrated in Figure 1 and Figure 2.

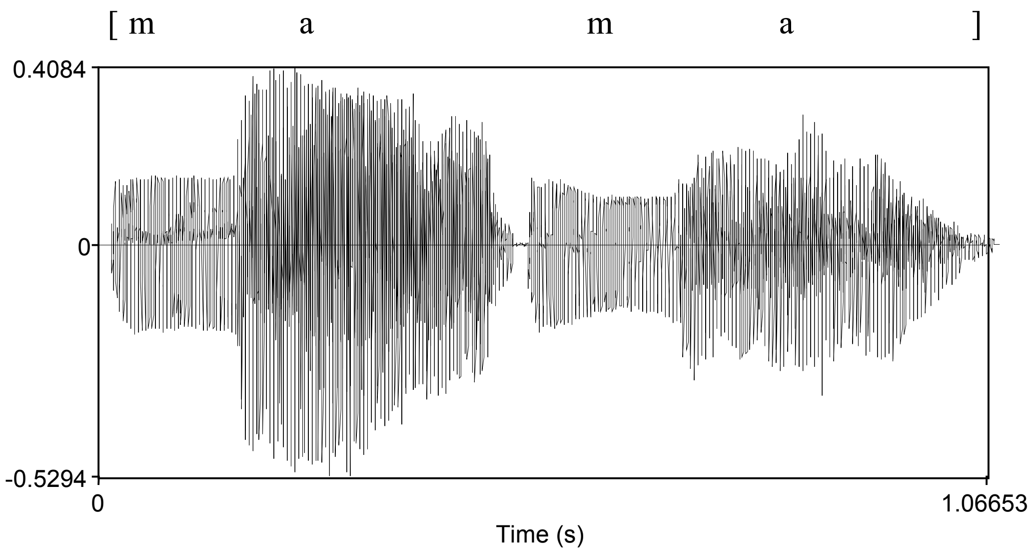

Figure 1 Waveform of syllables in Tones 1 and 6 with no final glottal stops: [ma].

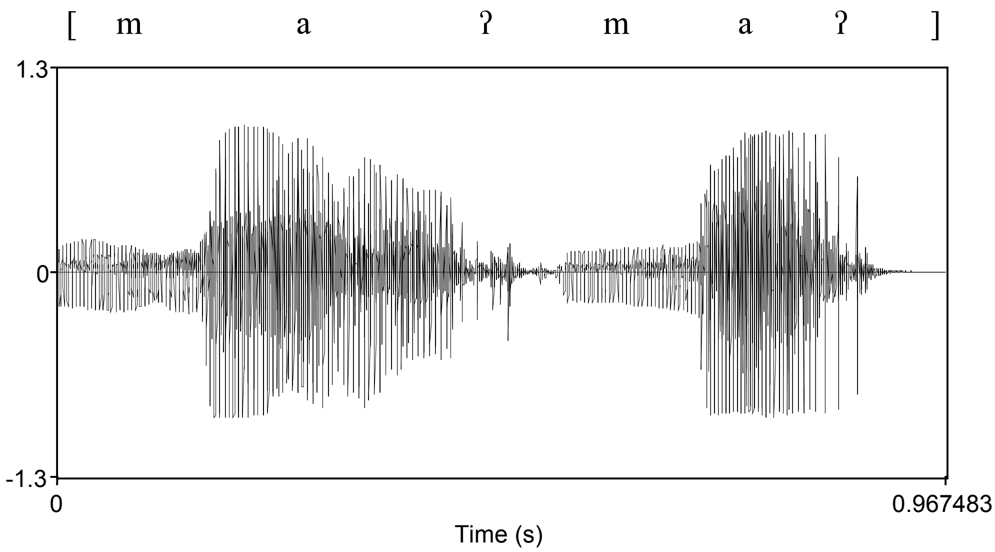

Figure 2 Waveforms of syllables in Tones 3 and 4, with irregular pulses indicating final glottal stops clearly visible: [maʔ].

In the case of Tones 2 and 5, there were mixed findings: four out of nine Tone 2 tokens and seven out of nine Tone 5 tokens had readily identifiable final /ʔ/. One interpretation of this, confirmed by the language consultant, is that the two tones may have been confused, and are interchangeable in her speech as a consequence of her dialect or mix of dialects. For the purposes of this paper, it is assumed that the reading produced in the majority of tokens is the intended one, namely that tone 2 should have no final glottal stop and Tone 5 should have a final glottal stop.

2.3.4 Fundamental frequency

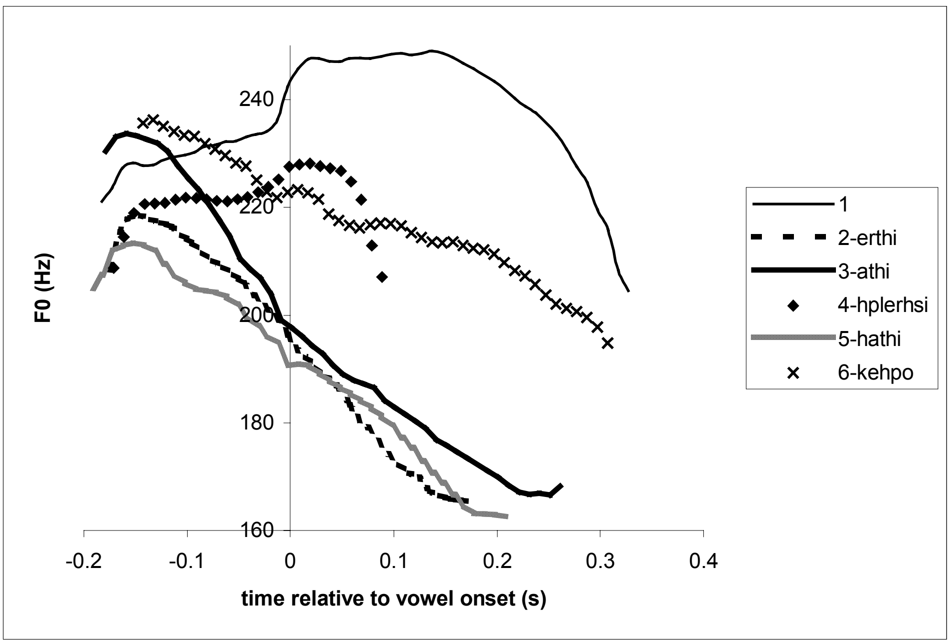

Figure 3 Fundamental frequency traces of a typical single syllable /ma/ in each of the six tones, aligned with the release of the nasal consonant at time = 0.

The F0 measurements reveal straight away one of the most interesting results of this study: that there is very little to tell tones 2,3 and 5 apart. In the restricted context of this experiment, all three have a mid to low falling contour, while Tone 1 is high, Tone 4 has a high to mid falling contour and Tone 6 is mid. The 'real time' F0 traces in Figure 3 may be compared with an illustration of the mean F0 measurements in Figure 4.

The significant effect of syllable set on the first quarter and mid-point measurements of F0 may be attributed to the predictable and often attested phenomenon of relatively higher frequency vowel onset after a voiceless stop /k/ consonant compared to a voiceless sonorant /m/ (see Hombert *et al.* 1979).

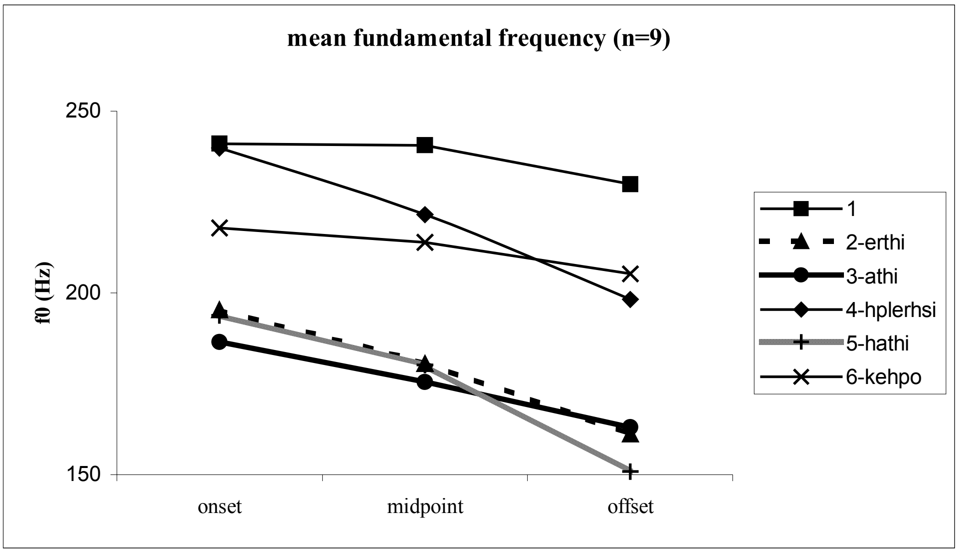

Figure 4 Mean F0 (n=9) in vowels of each tone, measured at three points evenly spaced through each.

2.3.5 Closed quotient

The results of the closed quotient measurements are particularly interesting, though not particularly clear, although tone is found to have a highly significant effect. Also at issue here is the presence or absence of final glottal stops. One can say with some confidence that Tones 1 and 6 are consistently relatively breathy, and that Tone 4 becomes progressively creakier as its final glottal stop approaches. Tone 3 appears to be relatively creaky, but CQ falls towards the final quarter. This unexpected finding is perhaps related to the preservation of a marked, creaky voice quality at a low F0. The CQ of Tones 2 and 5 is mid-range, with some divergence towards the end. If the mid-vowel CQ of these low F0 tones is said to indicate unmarked modal phonation, then the divergence of these two tones towards the final quarter – Tone 2 falling and Tone 5 rising – is consistent with Tone 5's mostly present final glottal stop and Tone 2's predominant lack of one.

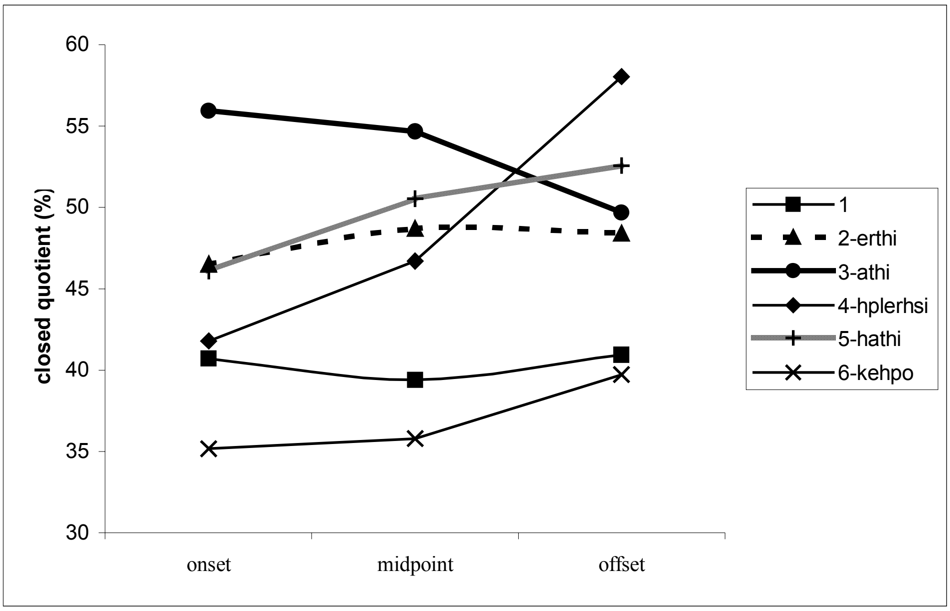

Figure 5 Mean CQ (n=9) in vowels of each tone, measured at three points evenly spaced through each.

2.3.6 Duration

The duration measurements illustrated in Figure 6 reflect the durational difference between the tones which is evident in Figure 3above. Tone and syllable set were both found to have a significant effect on duration, though there was no significant interaction between the two. A look at the data shows that vowels in the syllable set with initial /k/ were consistently shorter. The Scheffé test result shows very clearly that Tone 4 is shorter than the other five tones.

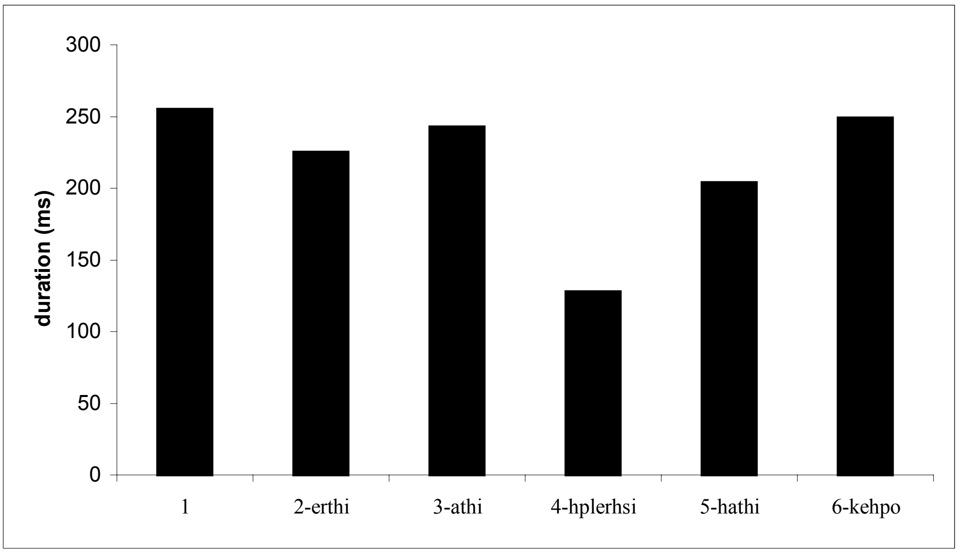

Figure 6 Mean duration (n=9) in vowels of each tone.

2.3.7 Vowel quality

The ANOVA test results show that both tone and syllable set have highly significant effect on all three formants. The syllable set effect can be accounted for by predictable formant transitions: after a bilabial initial we expect all three formants to start low, while after a velar initial we expect lower F1 and F2, and higher F2. The Scheffé comparisons suggest that the vowel quality of Tone 4 clearly distinguishes it from the other tones, and that it is the F1 rather than the F2 difference which sets Tone 4 apart, and so we may conclude tentatively that the /a/ vowel in this tone in more open.

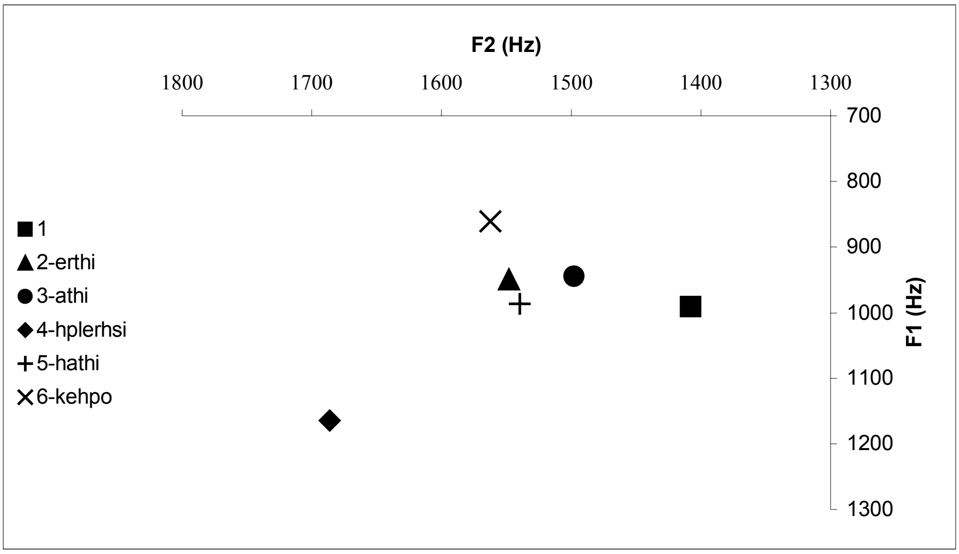

Figure 7 Vowel quality of Karen tones illustrated as mean F1 plotted against mean F2 (n=9).

2.3.8 Intensity and spectral tilt

The results of these two measures are inspected together, since it is expected that intensity and spectral tilt may be correlated, although no strongly significant statistical correlation is observed with these data. The ANOVA test found that syllable set has a significant effect on the first measurement of both intensity and spectral tilt, which can be accounted for by either by a positing that the phonation type at vowel onset can be expected to be relatively creakier after voiceless stops than after nasals, or that the sets of syllables were read at different speeds (syllable set had a significant effect on duration also).

Tone is a significant effect at all three points at which the measurements were made. The plots in Figure 8 and Figure 9 show a very clear result for Tone 4, which has greatest intensity and least spectral tilt, observations supported by the Scheffé comparisons in Table 5.

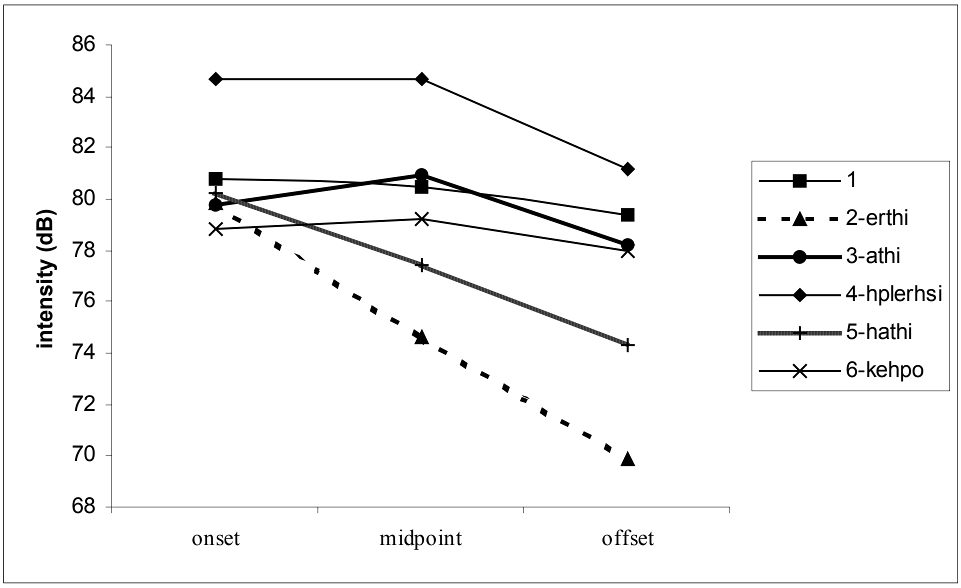

Figure 8 Mean (n=9) intensity of vowels in each tone, measured at three points evenly spaced through each.

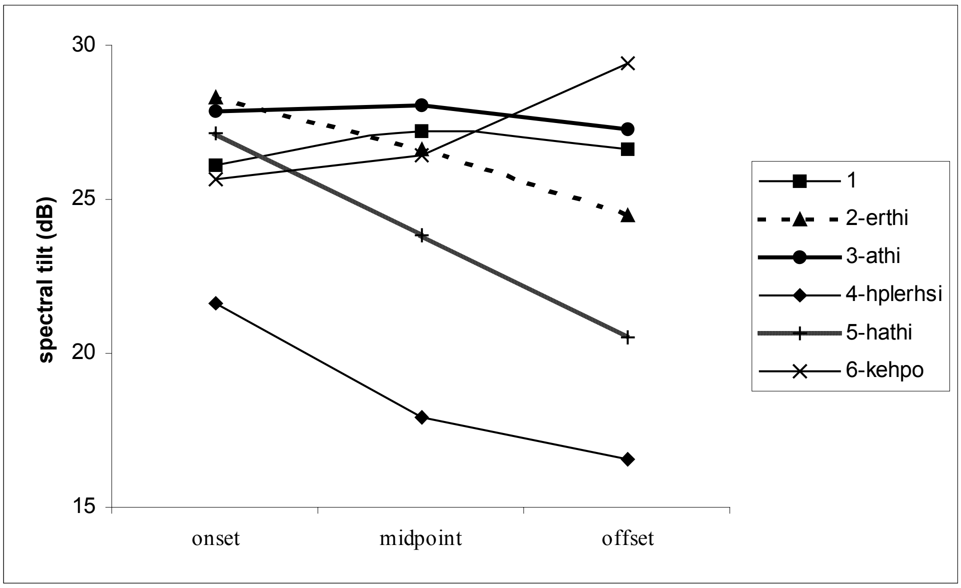

Figure 9 Mean (n=9) spectral tilt in vowels in each tone, measured at three points evenly spaced through each.

One unexpected finding here is that Tone 3 has been found to have creaky phonation but high spectral tilt; for the other tones, we find that spectral tilt correlates with phonation type in the predicted way.

2.3.9 Summary

From this set of measurements, we can propose a set of salient phonetic correlates, as set out in Table 6. Tones 2 and 5 remain problematic. The post-hoc Scheffé comparisons place them in homogeneous subsets for all the numerical variables and the status of the final glottal stop found in both of these tones is questionable.

Table 6 Sketch of proposed salient phonetic correlates of Karen tones in the context of this experiment.

tone	final /ʔ/	pitch	phonation	quantity	vowel quality	intensity	spectral tilt
1	no	high	breathy	long		mid	steep
2	?no	mid falling	modal	long		low	?
3	yes	mid falling	creaky	long		mid/low	steep
4	yes	high falling	creaky	short	more open	high	flat
5	?yes	mid falling	modal	long		low	?
6	no	mid level	breathy	long		mid	steep

3 Conclusions

How would Jones's 'pitch register' analysis play out against the phonetic data? Jones's own arrangement is given in Table 7. This array matches the phonetic data closely with regard to the phonation type measures. this arrangement tallies with Jones's own The problem surrounding the possible merging or confusing of Tones 2 and 5 will be left aside pending examination of further data, and we will concentrate on the remaining four tones.

Table 7 A 'pitch register' (Jones 1986) analysis of the six tones of Sgaw Karen.

syllable type	"high" register	"low" register
plain	5	2
breathy	1	6
stopped	4	3

How does this situation compare with other languages for which comparable data are available? In Yorùbá, voice quality (including phonation type) plays a rather minor supporting role in a predominantly pitch-led system of suprasegmental contrasts. In Wa, a language with a phonologically simple (though phonetically complex) register contrast, pitch is subordinate to a complex of voice quality features, with phonation type emerging as the most robust phonetic correlate of the contrast. In Burmese, some of the burden of contrast is carried by differences in syllable types (*killed tone*), and by duration: pitch and voice quality are usually required to indicate only binary contrasts.

In comparison with these three languages, we may observe that in the six tones of Karen, even after accounting for the cases where tonal contrasts are indicated by syllable type (final glottal stop), both pitch and voice quality seem to play a more substantial role in supplying potential acoustic cues to allow listeners to hear the difference between these tones. The final conclusion is that one might predict that within Jones's 'pitch register' model, pitch contours would be highly variable in the various contexts of connected or running speech, and that voice quality properties would remain robust.

A last comment is that all of these data are based on citation forms. To understand fully the implications of the present findings, it will be necessary to face up to the challenging prospect of analysing 'real-world' data. Another important component of future research should be perceptual tests to determine the relative robustness of pitch and voice quality contrasts in the ear of listeners.

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