European Scientific Journal June 2014 edition vol.10, No.17ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431

RELATIONSHIP BETWEEN LEXICAL TONE CONTRASTS AND VOWEL QUALITY

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Abstract

The language under study is Twi, a register tone language of the Kwa group, spoken in Ghana. It has a two tone system (high/low) and the downstep phenomena. The aim of this paper is two-fold. First, some phonological aspects of Twi tones are described. Second, acoustic measurements are carried out to investigate for differences between vowel quality in the two groups. In this analysis, two adult male speakers and one female adult speaker produced a series of isolated words belonging to the two phonological classes. The evidence from our acoustic data, confirming results obtained in a preliminary study, is for high tones to have higher fundamental frequency values than low tones. Acoustic results also confirm that high and low tones show sparse qualitative (F1, F2, F3 and F4) as well as sparse syllabic durational differences. The tendency is also for low tones to have lower F1, higher F2 than the high counterparts.

Keywords: Tones, F0, formants, vowel quality, duration

Introduction

The paper is divided into 3 main sections: the first part dealing with some phonological aspects of Twi vowels and Twi tonemics, the second section treats the methodology of the experimental analysis, and the last section presents observations and results of the acoustic investigations. Twi, spoken in Asante, uses tone for lexical and grammatical distinctions. It has a contrast between two pitch heights, and this occurs in words where the assigned syllable pitch is relatively higher or lower. An inventory of the phonological system of Twi shows that this language has 37 phonemically contrastive sounds: 23 consonant sounds, excluding allophones and loan phonemes (6 plosives, 4 nasals, 5 fricatives, 5 affricates, 1 trill and 2 approximants), and 14 vowel sounds: 9 oral vowels /i/, /ɪ/, /e/, /ɛ/, /a/, /ɔ/, /o/, /ʊ/, /u/ and 5 nasal vowels/ĩ/, /ɪ̃/, /ã/, /ʊ̃/and /ũ/.It must also be noted that phonemic quantity and nasality are phonologically distinctive in Twi.

Vowel quantity is used for lexical and grammatical distinctions, and nasality is used for lexical distinctions.

All Twi vowels and syllabic consonants carry tones (Creissels 1994, Dolphyne 1998). It has verbal tones, nominal tones, adjectival tones, adverbial tones and homotones.

Vowels of stem words can be divided into two categories: a class of verbs that always occurs with low tone and another class of verbs that always occurs with high tone. Continuative and stative forms of verbs carry low tones. For examplesõ /sʊ̃̀/'be big',wɔ /wɔ̀/'be located', de/dɪ̀/'be called', nam /nɑ̃̀m/'to be walking', gyina /ʤɪ̀ nɑ̃̀/'to stand', sɛ /sɛ̀/ 'to look like', kura /kù rà/'to hold', hyɛ /ʃɛ̀/'to be wearing/put on'. All verbal paradigms except the habitual carry low tones:pɛ /pɛ̀/'to like',nyane/ɲɑ̃̀ nɪ̃̀/'to wake', ware /wà rɪ̀/, wa /wà/, 'to be long',yɛ /jɛ̀/'to be',sɛ /sɛ̀/'to look like', kasa /kà sà/'to speak' bisa /bɪ̀ sà/'to ask'. Progressive and habitual forms of verbs carry high tones:sa /sá/ 'to dance', ka /ká/ 'to bite'dɔ /dɔ́/ 'to weed', di /dɪ́/ 'to eat',fa /fá/ 'to take', kɔ /kɔ́/'to go', tɔ /tɔ́/'to buy'.

Where there is verb serialization involving two different stems (i.e. verb plus verb constructions), the first stem carries a low tone and the second stem has a high tone: kɔ fa /kɔ̀ fá/ 'go and take', kɔ tɔ /kɔ̀ tɔ́/'go and buy'. Where there is verb reduplication, the two stems carry low tones: didi /dɪ̀ dɪ̀/ 'to eat' (plural form), fefe /fɪ̀ fɪ̀/ 'to suck, vomit'; (plural), bubu /bù bù/ 'to break' (plural) huhu /hù hù/'to blow' (plural), tete /tɪ̀ tɪ̀/ 'to tear' (plural).

The following register tone patterns: (1) High-High, (2) High-Low, (3) Low-High, (4) Low-Low in disyllabic morphemes, and (1) Low-Low-Low, (2) Low-Low-High, (3) Low-High-High and (4) High-High-High (5) High-High-Low (6) High-Low-Low in trisyllabic morphemes, found in other languages like Hausa and Acholi, all occur in Twi. Monosyllabic words have two possible patterns High-Low. These tone sequences have lexical and grammatical distinctions in Twi, features that are usually associated with West African languages.

Lexical contrast

Differences are made not based on absolute pitch, but on relative pitch in a word. Some examples of distinction between tone changes that are lexical are as follows: bra /brá/ 'life, existence' (noun) vs. bra /brà/ 'come'(verb), dada /dá dá/ 'old' (adjective) vs. dada /dà dà/ 'already' (adverb), da /dá/ 'to sleep' (verb), day' (noun) vs. da /dà/ 'never' (adverb).

Lexical grammatical contrast

Tone differences distinguish the habitual from the future, the habitual from the past forms, the negative from the imperative. Typical examples of lexical grammatical contrast are:ɔwɔ /ɔ̀ wɔ́/'snake' vs. ɔwɔ /ɔ̀ wɔ̀/'he/she possesses', ɔbɛfa /ɔ̀ bɛ́ fá/'he/she will take' vs./ɔ̀ bɛ̀ fà/'he/she comes to take',ɔdɔ /ɔ̀ dɔ́/'love' vs.ɔdɔ /ɔ̀ dɔ̀/'he/she loves'.

Homotones

In the category of homotones are words that exhibit the same tone patterns but have different meanings. Some examples of Twi homotones involving three tone patterns are as follows. First, Low-High patterns in dissyllabic words: ɔpɛ /ɔ̀ pɛ́/ 'he/she looks for'. ɔpɛ /ɔ̀ pɛ́/ 'Harmattan Winds', ɔyɛ /ɔ̀ jɛ́/ 'he/she is good, generous' vs. ɔyɛ /ɔ̀ jɛ́/ 'he/she insults'. Second, High pattern in monosyllabic words: da /dá/ 'day' vs. da /dá/ 'to sleep', ka /ká/ 'debt' vs. ka /ká/ 'to bite'. Third, Low-Low patterns; ɔwɔ/ɔ̀ wɔ̀/ 'he/she possesses' vs. ɔwɔ /ɔ̀ wɔ̀/ 'he/she is located', tete /tɪ̀ tɪ̀/ 'to tear (plural form) vs. tete /tɪ̀ tɪ̀/ 'ancient times'.

In this study, formant values of the target vowels are obtained in order to verify qualitative differences between high and low tones in the second syllable of the two syllabic morphemes. Results are provided for high and low tones, with specific relative pitches assigned to them, for the front oral vowel /ɛ/ under two consonantal environments /p/ and /s/.

Method

The data in this work consist of acoustic tone assignments obtained from one female and two male native Twi speakers, with no speech or hearing impairment, producing a series of Twi minimal pairs (words chosen to vary in tone assignment) containing high and low tones in isolated dissyllabic words, V_1CV_2, where V_1 = /ɔ/ and V_2 = /ɛ/. The speakers produced the utterances at a self-selected conversational rate in two consonantal environments /p/, /s/.

The randomised list of utterances was produced at least ten times by each speaker. The selected corpus of this investigation was made up of the following disyllabic words:

ɔpɛ /ɔ pɛ́/ 'he/she looks for', (habitual),

ɔpɛ /ɔ̀ pɛ́/ 'Harmattan Winds',

ɔpɛ /ɔ̀ pɛ̀/ 'he/she likes',

ɔsɛ /ɔ̀ sɛ́/ 'he/she spreads' (habitual), ɔsɛ /ɔ̀ sɛ̀/ ’he/she looks like’

Acoustic data were recorded in an anechoic room. First, by means of PRAAT sound editor, vowel durations were measured for the syllable CV and the target vowel. Second, FO values were calculated for the high tones and low tones, formant frequencies of vowels (F1, F2, F3, F4) were also measured for the two phonological classes at three equidistant points: at 25%, 50% and 75% of the duration of the vowel. The data were then averaged over the ten repetitions of each phonological category. Statistical analyses (ANOVAs) were carried out on all measures obtained from the three speakers ($p \leq 0.01$).

Results and Discussion

The basic trend in the data, F0 and formant value measures and standard deviations for the two sets of tone assignments are summarized in Tables 1, 2, 3 and 4 for one male speaker and in Tables 5, 6, 7 and 8 for the female speaker. The overall data indicate that the most important parameter for determining tone assignment contrasts, i.e. relative pitch, is highly significant ($p<0.001$).

In order to take a closer look at the tone assignments for the two phonological classes, average values for the male and female speakers were plotted on the same graphallowing comparison of analytical data (see figures 1 and 2).For the male speaker, absolute values show that the F0 for the low tone values vary between 104 Hz and 130 Hz and the high tone between 196 Hz and 251 Hz for the first pair /ɔ̀ pɛ̀/ vs. /ɔ̀ pɛ́/. The corresponding measurements for the second pair, /ɔ̀ sɛ̀/ vs. /ɔ̀ sɛ́/,are between 110 Hz and 145 Hz for the low tone and, between 188 Hz and 224 Hz for the high tone respectively (see figure 2). For the female speaker, absolute values show that F0 for the low tone values vary between 240 Hz and 243 Hz and the high tone between 260 Hz and 285 Hz for the first pair /ɔ̀ pɛ̀/ vs. /ɔ̀ pɛ́/ (see figure 1). The corresponding measurements for the second pair, /ɔ̀ sɛ̀/ vs. /ɔ̀ sɛ́/,are between 229 Hz and 243 Hz for the low tone and, between 256 Hz and 268 Hz for the high tone respectively (see figure 2).

Differences in average pitch (F0) values for low and high tones are greater for the male speaker (95 Hz on the average) than the female speaker. The corresponding average figure for the female speaker is 23 Hz (see figures 1 to 2). High tones demonstrate higher intensity values than low tones as dipicted in figures 3, 4, 5 and 6.

Figure 1: Average pitch (F0) values for low and high tones in /ɔ̀ pɛ̀/ vs./ɔ̀ pɛ́/(Hz).Each point is an average of 10 tokens produced by the female speaker and the first male speaker.

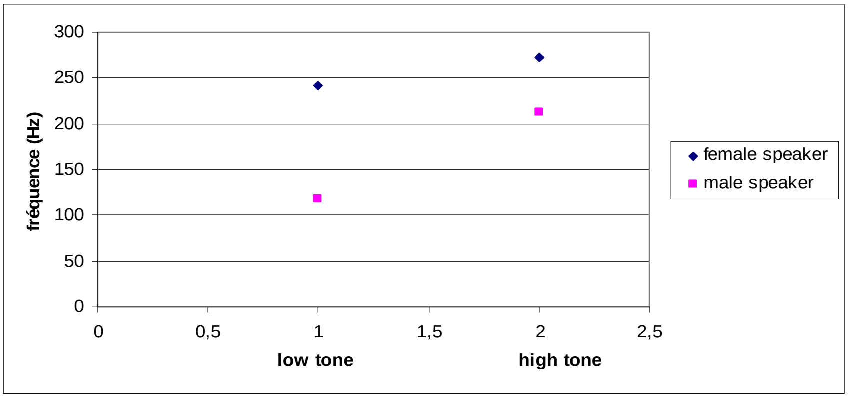


Figure 2: Average pitch (F0) values for low and high tones in /ɔ̀ sɛ̀/ vs./ɔ̀ sɛ́/(Hz).Each point is an average of 10 tokens produced by the female speaker and the first male speaker.

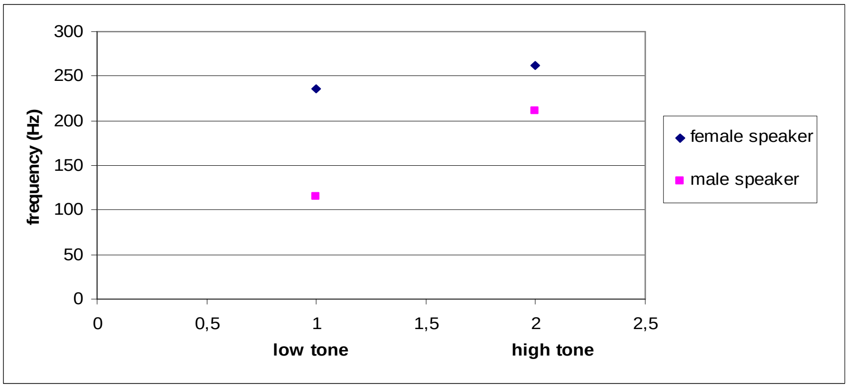


Figure 3: Waveform spectrograph, F0 (in blue), intensity curves (in yellow) and formants (in red) of /ɔ̀ sɛ́/; female speaker

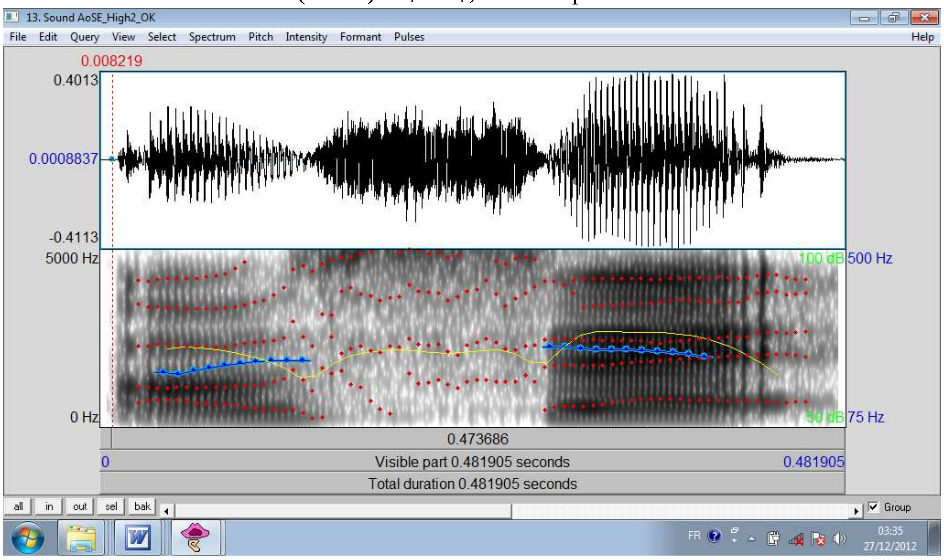


Figure 4: Waveform spectrograph, F0 (in blue), intensity curves (in yellow) and formants (in red) of /ɔ̀ sɛ́/; male speaker 2

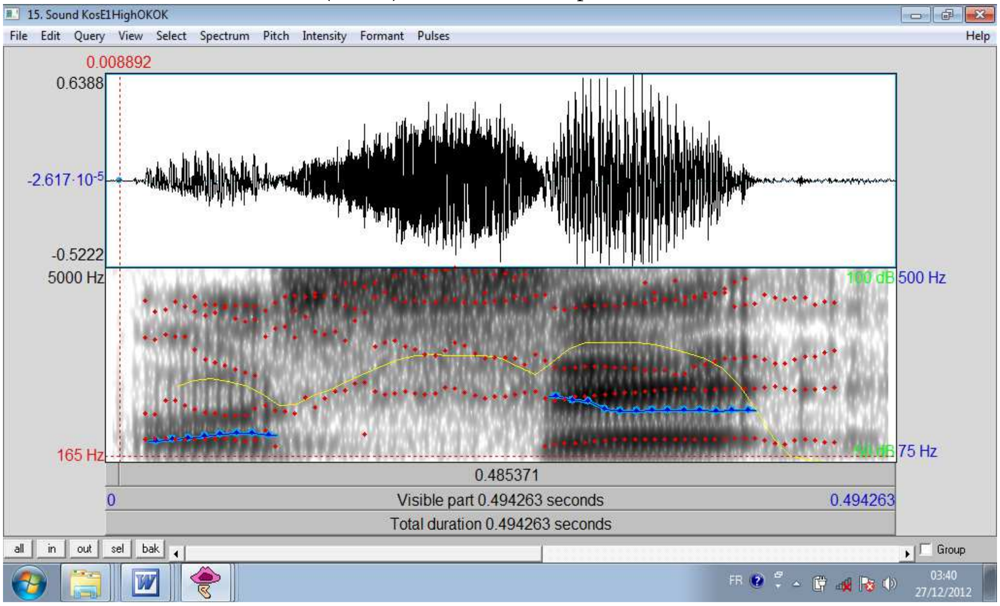


Figure 5: Waveform spectrograph, F0 (in blue), intensity curves (in yellow) and formants (in red) of /ɔ̀ sɛ̀/; female speaker

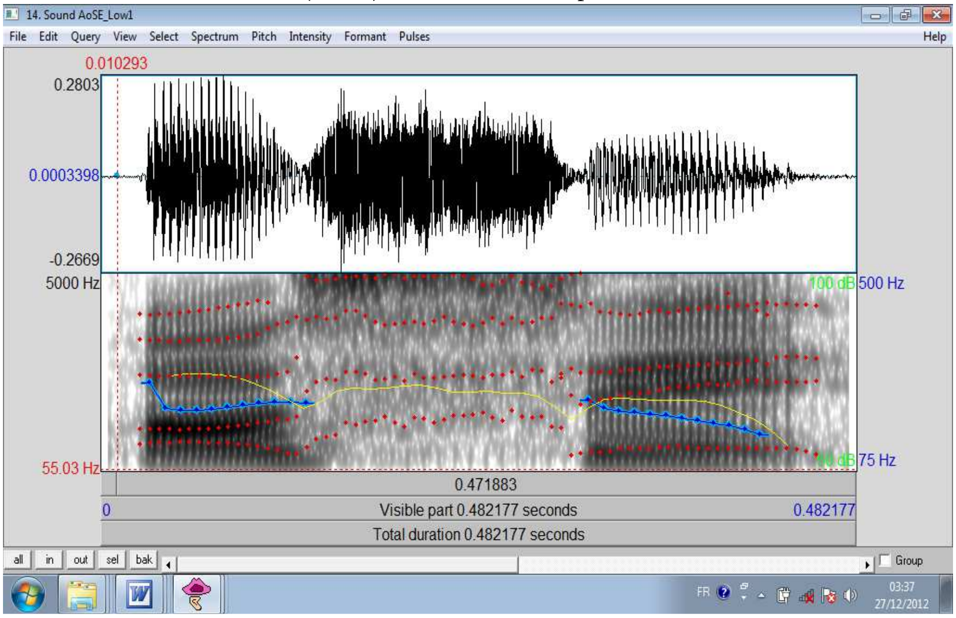
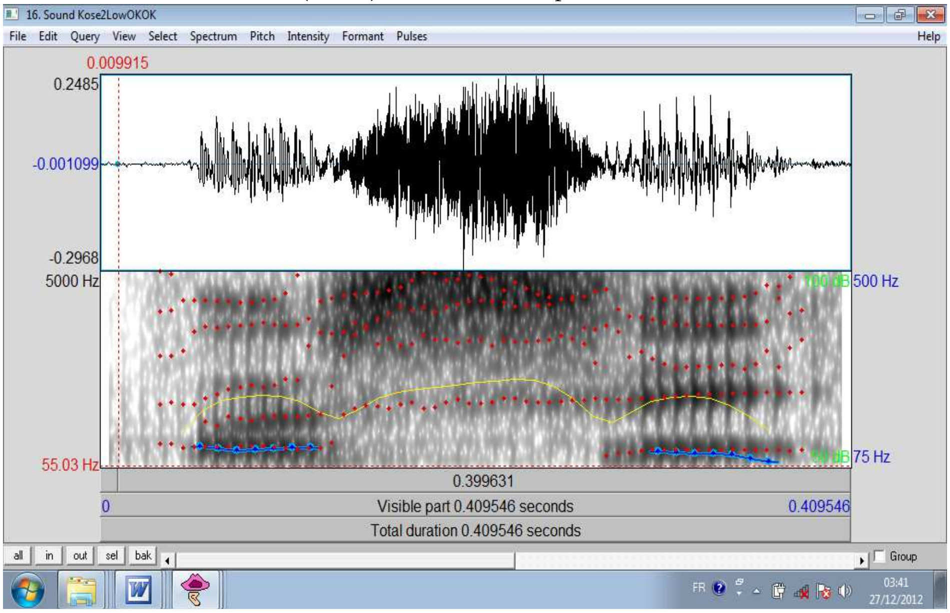


Figure 6: Waveform spectrograph, F0 (in blue), intensity curves (in yellow) and formants (in red) of /ɔ̀ sɛ̀/; male speaker 2



A close examination of formant values (F1, F2, F3 and F4) reveal that all phonological contrasts situate around pitch heights, and that sparse differences in formant structures of a given pair are non-significant. Acoustic results show that F1, F2, F3 and F4 values for low and high tones are quite similar (p=*ns*) for the male speaker, apart from F3 and F4 of the pair /ɔ̀ sɛ́/ and /ɔ̀ sɛ̀/. In this particular case, tone contrasts seem to be reinforced by differences in vowel quality. For the female speaker, acoustic results show that F1, F2, F3 and F4 values for low and high tones are quite similar (p=*ns*), apart from F3 and F4 values. In these two cases, tone contrasts seem to be reinforced by differences in vowel quality, especially F4 for the /ɔ̀ sɛ́/ vs. /ɔ̀ sɛ̀/ contrast.

Table 1: Average F0, formant values and standard deviations for the high tone in /ɔ̀ pɛ́/(Hz); male speaker

	F0	F1	F2	F3	F4
average	213	560	1794	2317	3603
standard deviation	14	29	66	138	208

Table 2: Average F0, formant values and standard deviations for the low tone in /ɔ̀ pɛ̀/(Hz); male speaker

	F0	F1	F2	F3	F4
average	118	496	1858	2530	3573
standard deviation	08	19	70	207	234

Table 3: Average F0, formant values and standard deviations for the high tone in/ɔ̀ sɛ́/ (Hz); male speaker

	F0	F1	F2	F3	F4
average	211	536	1770	2418	3990
standard deviation	11	43	76	115	146

Table 4:Average F0, formant values and standard deviations for the low tone in/ɔ̀ sɛ̀/(Hz); male speaker

	F0	F1	F2	F3	F4
Average	115	461	1823	2590	3737
standard deviation	11	17	66	291	143

Table 5:Average F0, formant values and standard deviations for the high tone in /ɔ̀ pɛ́/(Hz); female speaker.

	F0	F1	F2	F3	F4
average	273	670	2099	2687	3921
standard deviation	18	87	34	133	212

Table 6:Average F0, formant values and standard deviations for the low tone in /ɔ̀ pɛ̀/ (Hz); female speaker.

	F0	F1	F2	F3	F4
average	242	548	2125	2621	3718
standard deviation	02	82	103	164	325

Table 7: Average F0, formant values and standard deviations for the high tone in /ɔ̀ sɛ́/ (Hz); female speaker.

	F0	F1	F2	F3	F4
average	262	672	1857	2514	3380
standard deviation	08	92	100	107	380

Table 8: Average F0, formant values and standard deviations for the low tone in /ɔ̀ sɛ̀/(Hz); female speaker.

	F0	F1	F2	F3	F4
average	236	587	2011	2547	3808
standard deviation	10	42	134	113	323

/ɔ̀ pɛ̀/ and /ɔ̀ pɛ́/contrast

Acoustic results, especially formant values, and target vowel durations furnish some indications about the low and high tone contrasts. Acoustic data of the informants illustrate that F1, F2, F3 and F4 values for low and high tones are quite similar (p=*ns*). Acoustic data also show a general tendency where the low tone has a smaller F1 formant value than the high tone (see Tables 1 to 8). Contrary to the first formant values, the tendency is for the second and third formant values of the low tone to be greater than those of the high tone. The fourth formant values are smaller for the low tone compared to the high tone (see Tables 1, 2, 5 and 6). However, it must be noted that these readings represent minor formant value differences for the two phonological classes.

Acoustic investigations also show slight duration differences between the high and low tone with the former being slightly longer than the latter. Absolute duration values of the high tone range between 142 ms and 188 ms whereas the corresponding values for the low tone range between 52 ms and 95 ms for the male speaker. The average values of 10 tokens is 159 ms, with a relatively small standard deviation of 12 ms for the high tone. The corresponding average value for the low tone is 68 ms with a relatively small standard deviation of 14 ms.

/ɔ̀ sɛ̀/ and/ɔ̀ sɛ́/ contrast

Formant value analysis in this contrast confirms the fact that F1, F2, F3 and F4 values for low and high tones are quite similar (p=*ns*). Formant values also confirm the tendency observed for the preceding contrast (see Tables 1 to 8). The low tone has lower F1, higher F2, higher F3 and lower F4 values than the high tone. Like the previous category, acoustic data in this particular case show sparse syllable duration differences between the low and high tone with the high tone having a relatively longer duration than the low counterpart. For instance, absolute duration values of the vowel with high tone range from 107 ms to 178 ms for the male speaker. The corresponding values for the low tone range between 51 ms and 72 ms. The average value of 10 tokens is 144 ms, with a relatively small standard deviation of 22 ms for the high tone. The corresponding figure for the low tone is 60 ms with a relatively small standard deviation of 07 ms.

Given that F3 provides information about (i) the configuration of the labial cavity, and (ii) about protrusion of the lips and lip rounding. Given also that F2 indicates the front/back position of the tongue, i.e., the place of articulation, and that F1 gives information about the degree of aperture, i.e. the distance between the arch palate and the back of the tongue and on the position of the larynx (Calliope 1989), the following observations can be made about the low-high tone contrasts:

(a) The low tone tends to have a lower F1 formant value and a higher F2 value than the corresponding high tone. Low tone production (lower F1 and higher F2) could indicate a larger pharyngeal cavity compared to the configuration of the high tone.
(b) The comparison of the formant structures in the 2 categories shows a more compact vowel structure for the high tone (higher F1 and lower F2) compared to that of the low tone (lower F1 and higher).
(c) The formant structure also suggests a more advanced vowel and/or a higher vowel for the tone low tone compared to a less advanced vowel for the high tone.

Conclusion

In this investigation it has been shown, on the basis of the selected corpus and evidence from our acoustic data, that pitch difference is the determining factor in distinguishing high and low tone contrasts.

Formant value analysis, undertaken to verify vowel quality for the two phonological classes, reveals sparse qualitative differences. However, thanks to the acoustic data it has been possible to show that vowel formant values could help to distinguish the two classes, the slight tendencies notwithstanding.

The low tone tends to have a smaller F1 and greater F2 values than the high tone. Low tone production (lower F1 and higher F2) could indicate an expanded or bigger pharyngal cavity than the high tone.

Formant structure comparison of the two classes indicates a more compact vowel structure for the high tone (higher F1 and lower F2) compared to that of the low tone (lower F1 and higher F2). The formant structures also suggest vowel quality that is more fronted and/or raised for the low tone compared to a vowel quality that is more retracted for the high tone.

The next step of this study is four-fold. First, to investigate formant value differences between high and low tone contrasts for the remaining oral and the nasal vowels with data based on more speakers. Second, to undertake a thorough articulatory study in order to investigate for further information on the vocal tract during the production of the two phonological contrasts, i.e. what are the articulatory factors underlying the production of tone contrasts? Third, apart from formant frequencies, it should be worthwhile looking at other kinds of acoustic information like amplitudes and bandwidths, e.g. relative amplitude of lower and higher harmonics (H1-H2). Fourth, to investigate voice onset times which may also vary with tonal identity.

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