The Five Phonemic Vowel Heights of Southern Sotho: an Acoustic and Phonological Analysis

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Abstract: This study examines the vowels of Southern Sotho, a South African language of the South Eastern Bantu group. The purpose of this work is to determine the actual number of Southern Sotho phonemic vowel heights and their acoustic characteristics. Some authors claim that there are seven phonemic vowels, making four phonemic heights, and that this number of vowels increases as a result of the process of vowel raising giving then eleven phonetic vowels and six phonetic vowel heights.

An acoustic analysis of all Southern Sotho vowels was made in order to determine their spectral qualities. Measurements were taken of the first three formants and their corresponding bandwidths. Two male speakers were recorded uttering the vowels under the same conditions. The speakers varied significantly in age, dialect, formant frequencies, bandwidth and pitch. Despite these differences, however, variation in formant frequency according to vowel height was the same for both speakers. This indicates that the vowel heights are realized acoustically in the same way by both speakers. The acoustic measurements support the claim made in this work that there are nine phonemic vowels, which constitute five phonemic heights. Since standard *Sound Pattern of English* (SPE) features do not distinguish five phonemic heights, the additional feature [Expanded], suggested by Lindau (1975), is recommended in order to distinguish these vowels.

1. INTRODUCTION

1.1. Southern Sotho

Southern Sotho, generally known as Sesotho, is a South African language spoken by the Basotho in Lesotho. It is also spoken by about half the population of the Orange Free State, about a quarter of the Transvaal, and by some in the Cape Province and in Natal.

1.2. The Problem of Determining the Number of Phonemic Vowel Heights in Southern Sotho

One problem we are faced with concerning Southern Sotho is a lack of certainty as to how many phonemic vowels there are in the language. Clarification is also needed concerning the number of phonetic vowels. That these constitute problems is evidenced by the conflicting claims made by different authors regarding the number of Southern Sotho vowels. Most authors believe that there are seven phonemic vowels in Southern Sotho, viz. /i e ɛ a ɔ o u/ (Figure 1). All other additional vowel sounds heard in everyday speech are the result of phonological rules.

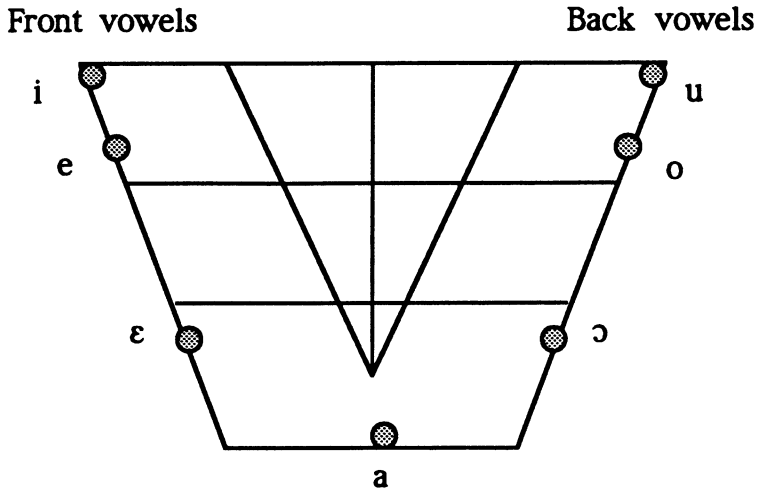

Figure 1: A phonemic chart of Southern Sotho vowels based on Doke & Mofokeng's model (1974), showing seven phonemic vowels.

This proposal would work if there were only a few exceptions to the phonological rules. But the fact is that Southern Sotho has quite a large number of words containing vowels that are not derived from these rules. These vowels are not among the seven phonemic vowels shown above nor are they the result of any rule. Rather, they constitute a fifth, unpredictable vowel height. Figure 2 indicates this additional vowel height with circles; the front sound is ɛ̣ and the back sound is ɔ̣.

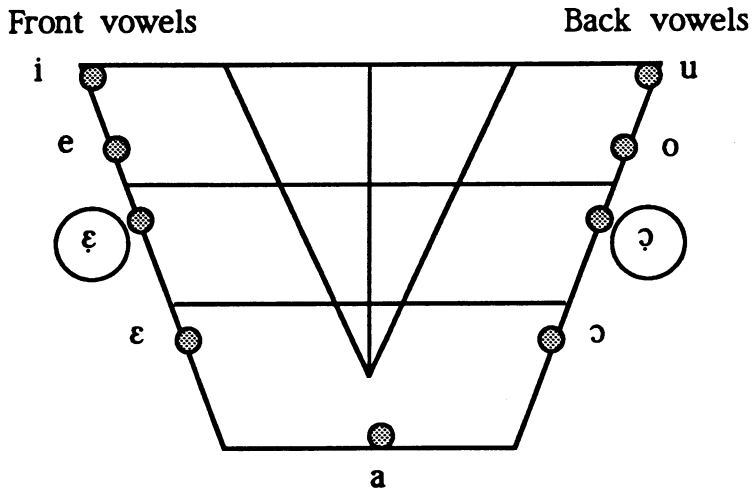

Figure 2: A phonemic vowel chart of Southern Sotho vowels, showing a fifth phonemic vowel height (encircled). The phonemic vowels are nine in number.

Figure 3 illustrates the eleven phonetic vowels of Sesotho.

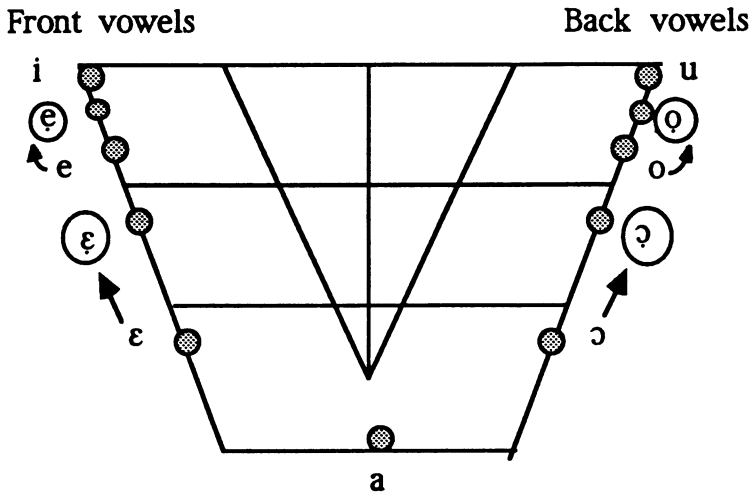

Figure 3: A vowel chart of the eleven Southern Sotho vowels with arrows indicating how some sounds are related to others by the process of vowel raising.

The encircled vowels indicate sounds that result from a rule of vowel raising (see section 4). This rule applies when certain vowels are followed by higher vowels. Thus, if /ɛ/ and /ɔ/ are followed by one of the vowels /i e u o/, /ɛ/ becomes [ɛ̨] and /ɔ/ becomes [ɔ̨]. (The transcription of these raised vowels indicates provisionally that they are at the same height as the two additional vowel phonemes mentioned on the preceding page. This

identity of vowel height will be confirmed by the acoustic analysis in section 3.) Moreover, if /e/ and /o/ are followed by /i/ or /u/, /e/ becomes [ɐ] and /o/ becomes [ɔ]. This is illustrated by the following examples[1]:

ho léka [ho leka] (to try)	ho lékiṣa [ho lɐkisa] (to imitate)
ho leka [ho lɛka] (to lick)	ho lekisa [ho lɐkisa] (to cause to lick)
ho loka [ho loka] (to be kind)	ho lokisa [ho lɔkisa] (to repair)
ho kólóka [ho kɔlɔka] (to form a line)	kólókisa [kɔlɔkisa] (arrange in lines)

The sounds /ɐ/ and /ɔ/ can, however, also occur when not followed by a higher vowel, as shown below (see further examples in Appendix):

lékétla [lɐkɐtla] (hang)	mokótla [mokɔtla] (a bag)
thépe [thɐpɐ] (a kind of vegetable)	lekópokópo [lekɔpɔkɔpɔ] (a big can)

To support this claim, however, it is necessary to have acoustic measurements of the vowels. From this we can determine whether or not the proposed nine phonemic vowels are different in height and, moreover, how different they are from each other.

1.3. Literature Review

Tucker (1969) distinguishes between "seven main vowel sounds", /i e ɛ a ɔ o u/, and two "open varieties", ɐ and ɔ. Roux (1982) provides a cardinal vowel chart representing these sounds (see Figure 4). The vowels ɐ and ɔ are regarded as variants of both e/o and ɛ/ɔ, i.e. as "lowered/opened" variants of e/o and "raised/closed" variants of ɛ/ɔ.

Doke & Mofokeng (1974) distinguish seven phonemic vowels: /i ɨ ɛ a ɔ ʉ u/, and nine phonetic ones, adding [e o] to these. In the Southern Sotho orthography used in their study, the phonemic vowels are written as <i, ē, è, a, ò, ō, u >. However, they do not refer to [e o] as "lowered/opened" variants of higher vowels as Tucker does (see Figure 5).

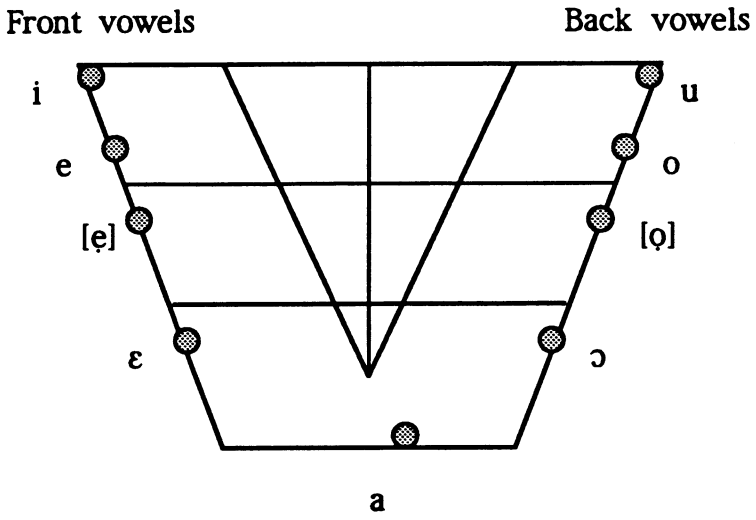

Figure 4: Roux's chart of Tucker's vowel sounds, showing seven main sounds and two "open varieties" ẹ/ọ, regarded both as the "lowered/opened" variants of e/o and the "raised/closed" variants of ɛ/ɔ.

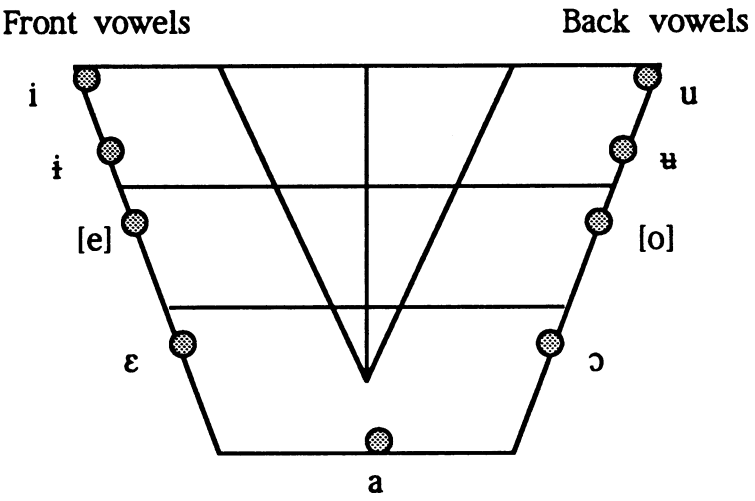

Figure 5: Doke & Mofokeng's model of vowel sounds, showing seven phonemic vowels and nine phonetic vowels.

Doke & Mofokeng recognize three types of e (our phonetic [ɛ̣]):

i) permuted è /ɛ/, i.e. occurrence of a higher variant e [ɛ̣] governed by phonetic considerations, e.g.

tsèbè (ear) > tsebeng (in the ear)
fèla (come to an end) > fedisa (finish)

N.B. The grave accent indicates the particular vowel quality, not low tone.

ii) uninfluenced e, i.e. occurrences of a higher variant e [ɛ̣] *not* governed by phonetic considerations, e.g.

jwale (now)
hae (home)
maele (wisdom)

iii) final e[ɛ̣] alternating with è [ɛ] according to the speaker, e.g.

sefate (tree) ~ sefatè (tree)

They also divide o (our phonetic [ɔ̣]) into two types:

i) permuted ò /ɔ/, the occurrence of o [ɔ̣] governed by phonetic considerations, e.g. : phòòfòlò (animal) > phoofolong (on the animal)

ii) uninfluenced o [ɔ̣] e.g. : bo-ntate (fathers)

Doke & Mofokeng add that when applying "narrow phonetic principles" the vowels /ɛ/ and /ɛ̣/, /ɔ/ and /ɔ̣/ may also be considered separate phonemes. They provide several minimal pairs (p.5) such as:

/ɛ/ sèla (buy food in time of scarcity) /ɔ/ hòna (it)
/ɛ̣/ sela (that yonder) /ɔ̣/ hona (this)

However, in their later discussion they treat [ɛ̣ ɛ] and [ɔ̣ ɔ] as members of the same phoneme, on grounds of their phonological relatedness (pp.7-8).

To summarize, both Tucker and Doke & Mofokeng distinguish seven phonemic vowels. Tucker claims that there are also two "open varieties" which can be either the "lowered" or "raised" variants of other phonemic vowels, whereas Doke & Mofokeng divide the upper mid vowels [ɛ̣], [ɔ̣] into two subtypes: one, derivable by phonetic rules, and the other, not derivable by phonetic rules; they do not take a consistent position on their phonemic status. It is because of these conflicting claims and the uncertainty about

the actual number of Southern Sotho vowels in the literature that the present study is necessary.

1.4. Purpose of this Study

We claim that /ɐ/ and /ɛ/ are separate phonemes, i.e. that it is not the case that [ɐ] is always derived from /ɛ/. This claim also applies to the back sounds /ɔ̩/ and /ɔ/; they are also phonemically distinct in some contexts. It is important to note that it is not the case, as Tucker claims, that ɐ and ɔ̩ are the lower/open variants of /e/ and /o/ respectively. We thus revise Roux's model of Tucker's vowel sounds (Figure 4) as shown in Figure 6 to illustrate the position of /ɐ ɔ̩/ as a distinct phonemic height, and not one which is derived from other sounds. The following words exemplify the difference between these three heights as well as the contrast between /ɛ/ and /ɐ/, /ɔ/ and /ɔ̩/. Refer to the Appendix for more examples of the latter contrasts.

/e/	/ɐ/	/ɛ/
tebetébe /tebetebe/	thépe /thɐpɐ/	thébe /thɛbɛ/
(muddy place)	(kind of vegetable)	(shield)
-petla /petla/	-hetla /hɐtla/	betla /bɛtla/
(ooze)	(look back)	(sharpen)
-sena /sena/	sena /sɐna/	-sela /sɛla/
(to grin)	(this)	(to hunt)
mokéte /mokete/	molékétla /molɐkɐtla/	mokéke /mokɛkɛ/
(feast)	(long hanging object)	(big dish)

/o/	/ɔ̩/	/ɔ/
-hóhla /hoła/	hóhle /hɔ̩łɐ/	-phótla /phɔtla/
(scrub)	(all over)	(wash face)
ho na /hona/	hona /hɔ̩na/	hona /hɔna/
(to rain)	(this)	(it)
mokóko /mokoko/	mokólóko /mokɔ̩lɔ̩kɔ̩/	mokólóbo /mokɔlɔbɔ/
(rooster)	(procession)	(state of being wet)
lethópa /lethopa/	motópótla /motɔ̩pɔ̩tla/	tóro /tɔrɔ/
(boil)	(unhappy person)	(dream)

The minimal or near-minimal contrasts illustrated above make it necessary to consider the following nine vowels as phonemic in Southern Sotho: /i e ɐ ɛ a ɔ ɔ̩ o u/. To this we add two more vowels, raised [ẹ] and [ọ], which are derived from /e/ and /o/, respectively, under the influence of a follow-

ing /i/ or /u/. This brings the total number of phonetic vowels in Southern Sotho to eleven: [i ẹ e ẹ ɛ a ɔ ọ o ọ u] (see Figures 6 and 7).

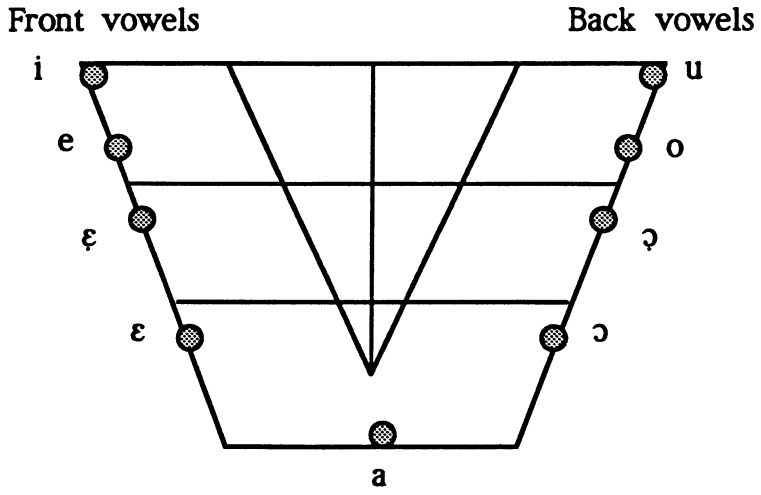

Figure 6: A vowel chart illustrating the new analysis, with nine phonemic vowels.

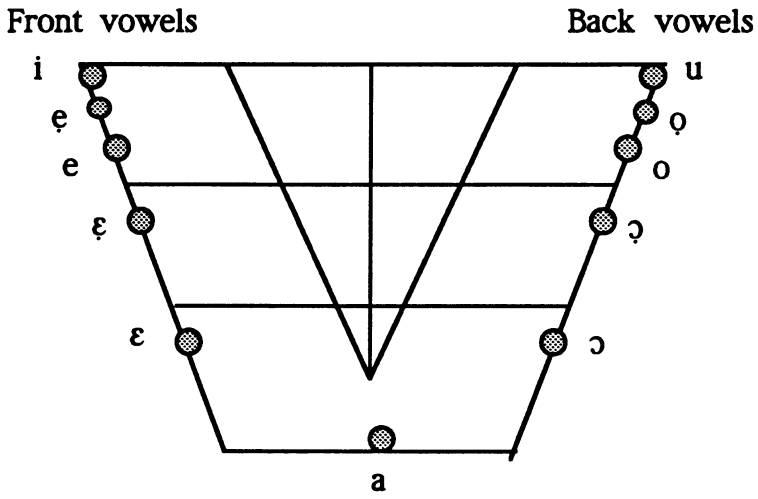

Figure 7: A vowel chart showing the eleven Southern Sotho phonetic vowels.

Of special interest to us, then, are the occurrences of "uninfluenced" or phonemic [ẹ ọ], i.e. those not governed by phonetic rules (Doke & Mofokeng 1974). Therefore, these sounds constitute the focus of this study. Our objectives are the following:

1. To determine through acoustic analysis the height of the front vowel [ẹ] and the back vowel [ọ], in relation to other vowel heights.

2. To determine whether the vowels [ɛ̨], [ɔ̨] derived from the phonemes /ɛ/, /ɔ/ through a process of Vowel Raising (section 4) are phonetically distinct from "uninfluenced" or phonemic [ɛ̨], [ɔ̨].
3. To investigate the need for an additional vowel feature from those proposed in *The Sound Pattern of English* (SPE) in order to distinguish the height of /ɛ̨ ɔ̨/ from other vowel heights.

2. SOUTHERN SOTHO VOWEL ANALYSIS AND COMPARISON OF SPEAKERS: RESEARCH METHODOLOGY

2.1. Methods

In preparation for acoustic measurements, recordings of the words to be analyzed were made in a sound-treated room in the Phonetics Laboratory of the Department of Modern Languages and Linguistics, Cornell University, in the following way:

Step 1. The test words were recorded on an Ampex reel-to-reel recorder. Two males, both native speakers of Southern Sotho, were recorded individually without rehearsing the words before recording. Male subjects were chosen because formant frequencies are usually easier to measure in men's speech than in women's speech. These two subjects were of different ages and dialects. One, a 33 year old adult, was from the central Transvaal area, a Johannesburg district, and the other, a 14 year old boy, was from Orange Free State and grew up in Ficksburg and Welkom.

Thirteen Southern Sotho words were recorded. In these words the 13 vowels were placed in a similar environment, i.e. between a velar stop /k/ or a velar aspirated stop /kh/ and an alveolar stop /t/, a lateral alveolar affricate /tl/, or a lateral alveolar fricative /ɬ/ (spelled hl). Finding a similar environment in meaningful words for all the vowels was a difficult task which was made even more difficult by also trying to have the same tone on the vowels in question. Where words with the same tone or consonant were not found, the closest word to the conditions was selected. As a result, the environments differed slightly because of the desire to use meaningful words, as well as the same tone in the vowel under comparison, in this case high tone. The words are:

Front vowel words:		**Back vowel words:**	
/i/	pikitla (rub)	/u/ ikútlwa	(hear oneself)
[ɛ̨]	ikétile (has been romantic)	[ɔ̨] ikhóhlile	(has rubbed oneself against)

/e/	ikéta (being romantic)	/o/ mokóta	(feces)
/ɛ̩/	lékétla (hanging)	/ɔ̩/ mokótla	(sack)
[ɛ̩]	ikétlile (has relaxed)	[ɔ̩] ikótlile	(has hit oneself)
/ɛ/	ikétla (relax)	/ɔ/ ikótla	(hit oneself)
		/a/ ikátla	(hold oneself)

Notice that ɛ̩ and ɔ̩ both occur twice in the list, once as a basic vowel and once as a derived vowel. / / marks a basic (phonemic) sound, one which is not governed by phonetic rules, and [ ] marks a derived (phonetic) sound, one which occurs under the influence of a following higher sound, in this case /i/. In other words, we examined the phonemic, uninfluenced sounds /ɛ̩/ and /ɔ̩/ separately from the vowels which arise as a result of the vowel raising process, namely the derived sounds [ɛ̩] and [ɔ̩].

Each word was repeated 12 times. The 10 middle repetitions were analyzed and average values for fundamental frequency, formant frequencies and bandwidths were determined. Each word was read in the carrier phrase "e re ___ hape" (say ___ please), to maintain the same stress for each vowel.

Step 2. The recorded material was digitized at 10 kHz into a Sun 3/160 using custom speech analysis software. The analysis of vowels was done as follows:

a) The target vowels were identified in the waveform display.
b) A wide-band spectrogram of each target vowel was displayed on the computer screen.
c) Plots of formant frequencies, obtained by linear predictive coding (LPC), were superimposed on the spectrogram.
d) For the first three formants, F1, F2, F3, measurements were taken in the middle of each vowel for both their frequencies (F_1, F_2, F_3) and bandwidths (B_1, B_2, B_3).
e) The fundamental frequency, FO, for each vowel was also taken at this point in each vowel.

Step 3. The measurements made on the Sun were transferred to a Macintosh for statistical analysis, using the Statview 512 package. The data were arranged in categories of FO, F1, B1, F2, B2, F3, B3, the number of the repetition, the test word, and vowel features, for each speaker.

In considering the nine vowels of Sesotho to be phonemic, as claimed in section 1.4., we expect them to have different formant frequencies (F),

bandwidths (B), and perhaps also pitch (FO), since pitch can vary directly with vowel height. In section 3, we analyze the spectral qualities of these vowels.

In addition, however, it is necessary to test whether the acoustic differences between vowel heights vary with the difference between speakers, in age or dialect. Analyses of variance (ANOVA) were run to determine the influence of the two sets of independent variables on the results. The following independent variables were used in the two ANOVAs:

a) individual speakers (distinguished by age):

Speaker A, 33 years old; Speaker B, 14 years old.

b) individual vowels (as distinguished by their features):[2]

/i/	+ h + e
[ẹ]	- h + e
/e/	- h - e
/ɛ̣/	+ l + e
[ɛ̣]	+ l + e + d
/ɛ/	+ l - e
/a/	+ l - r + b
/ɔ/	+ l - e + b
[ɔ̣]	+ l + e + b + d
/ɔ̣/	+ l + e + b
/o/	- h - e + b
[o̞]	- h + e + b
/u/	+ h + e + b

2.2. Results: Speaker Differences

The two speakers in this study differ in age and dialect, as mentioned above. Speaker A has, in general, a lower voice, reflected both in pitch (see Figure 14) and formant frequencies (see Figures 8, 9, and 10). Both differences are expected since as an adult, his vocal tract is larger than that of speaker B.

2.2.1 Formant Frequency

The results of a one factor ANOVA, in which the independent variable is "speakers" and dependent variables are F1, F2 and F3, show a significant difference in frequency between the two speakers: $F(1, 258)=18.185$, $p < .0001$ for F1; $F(1, 258)=8.318$, $p = .0043$ for F2; and $F(1,258)=63.105$, $p < .0001$ for F3.

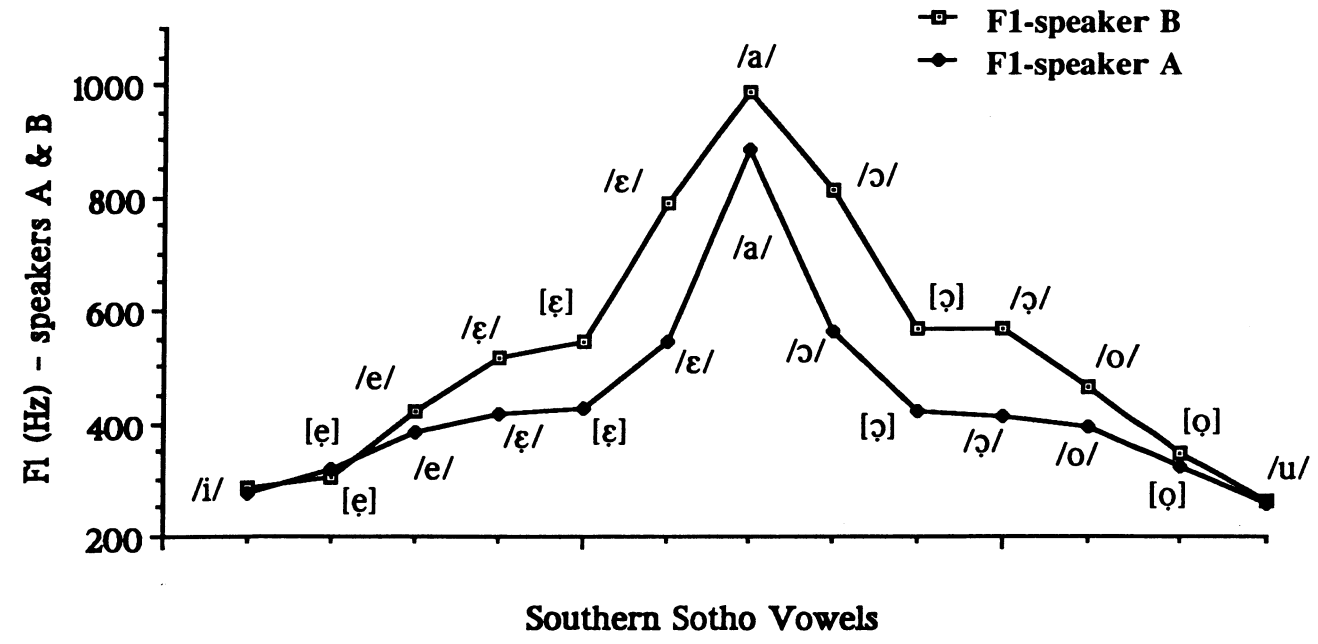

Figure 8: Mean first formant frequencies for speaker A and speaker B.

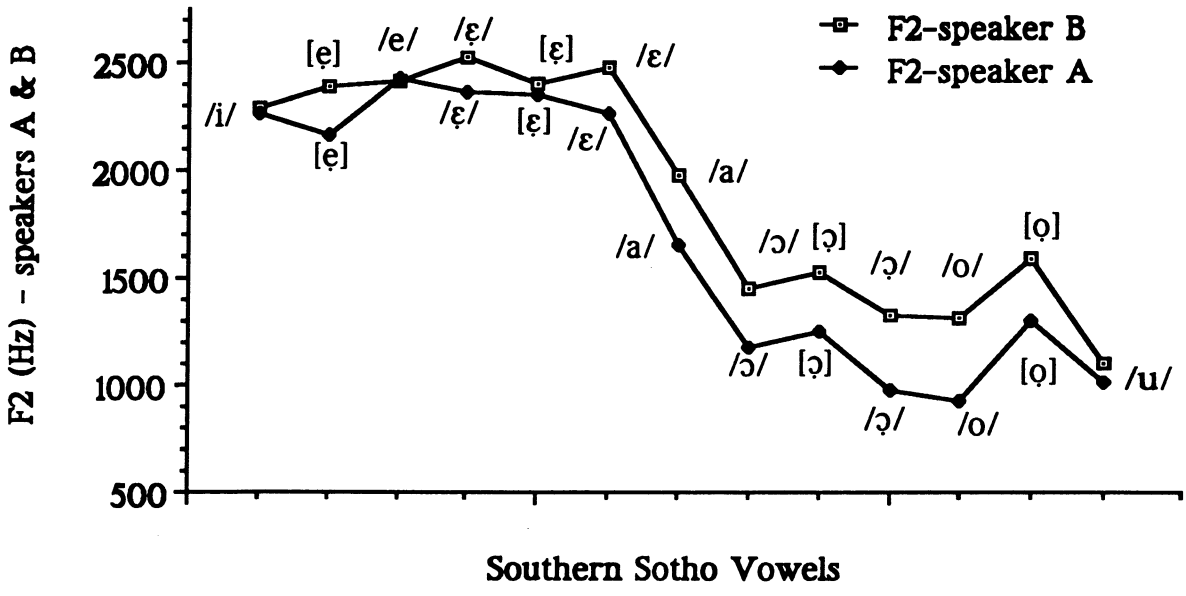

Figure 9: Mean second formant frequencies for speakers A and B.

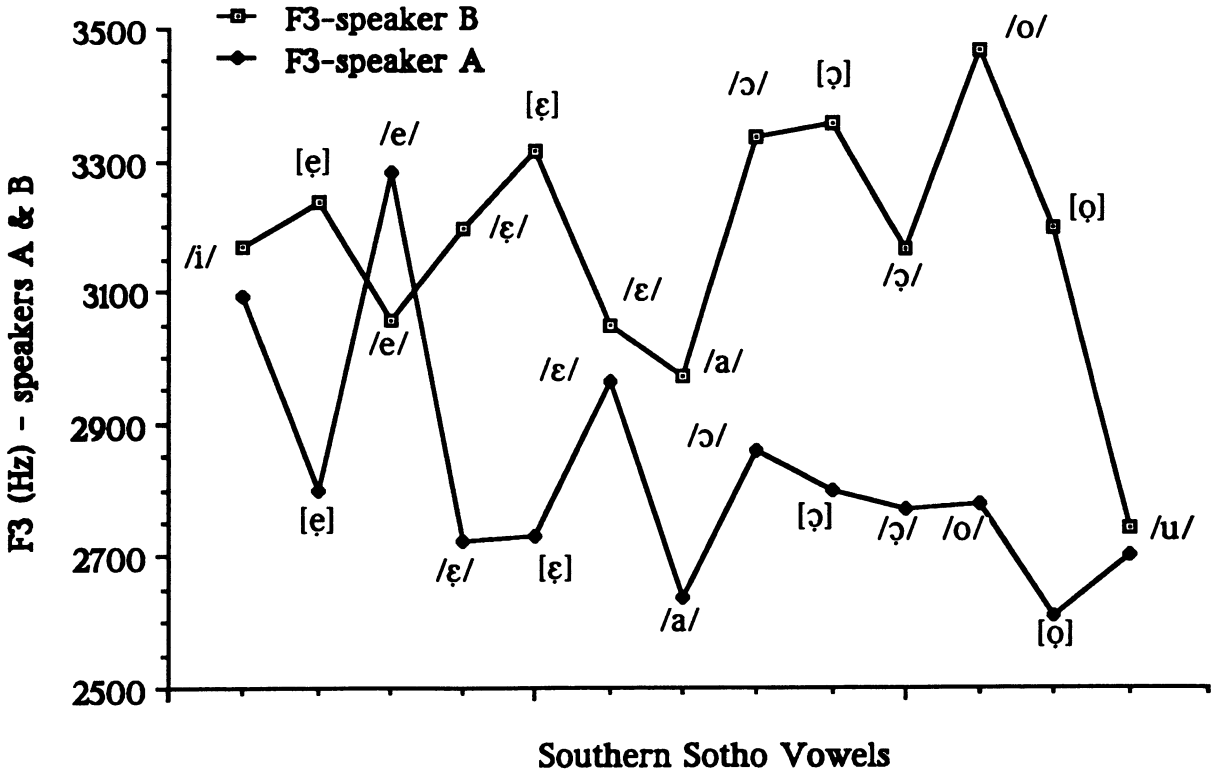

Figure 10: Mean third formant frequencies for speakers A and B.

2.2.2. Bandwidth

The amplitude of a formant was measured in terms of its bandwidth. In general, a large bandwidth corresponds to a low amplitude, and vice versa. The bandwidths of all three formants are smaller for nearly all vowels for speaker A than for speaker B (see Figures 11, 12, and 13). Irregularities are found, however, in the first formant of /a/ (Figure 11) where speaker A has the largest bandwidth and speaker B has the smallest bandwidth. A greater difference is observed in the bandwidth of the third formant (Figure 13) where speaker A has a larger bandwidth in the higher front vowels, as well as [ɛ̣ ọ], than speaker B.

The results of a one factor ANOVA in which the independent variable is "speakers" and the dependent variables are B1, B2 and B3, show that the differences in bandwidth between the two speakers are significant for the two lower formants: $F(1, 258)=11.435$, $p = .0008$ for B1, $F(1, 258)=5.193$, $p = 0.0235$ for B2, but don't quite reach significance for B3: $F(1, 258)=3.648$, $p = 0.0573$ for B3.

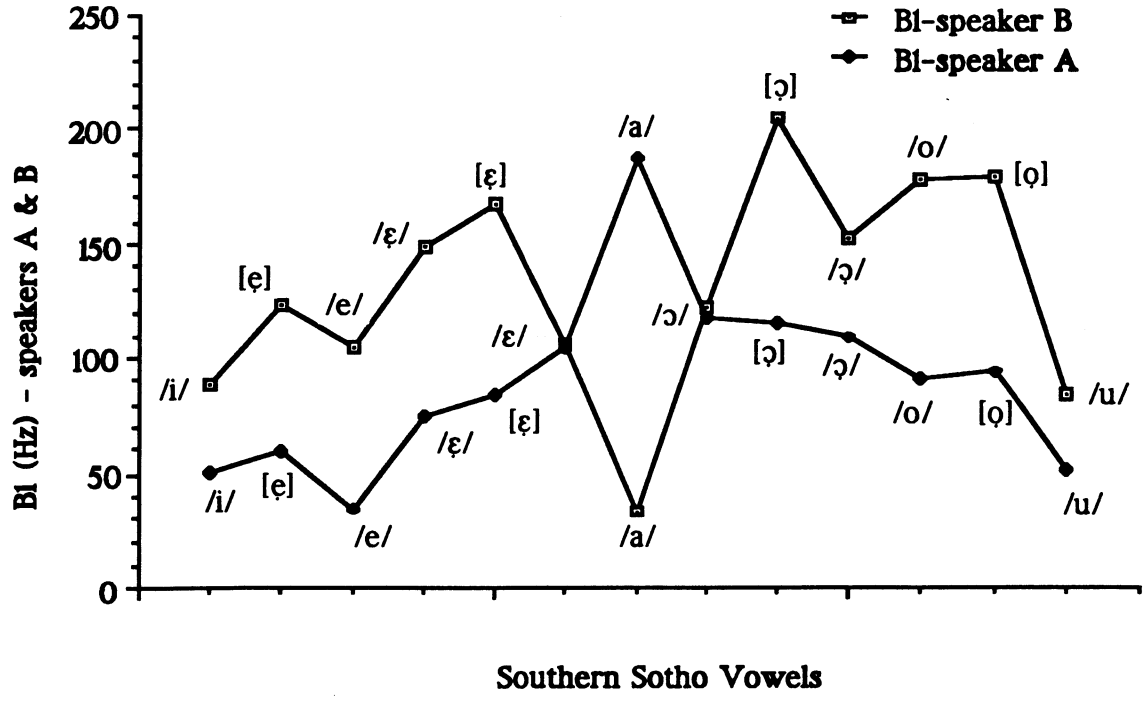

Figure 11: Mean first formant bandwidths for speakers A and B.

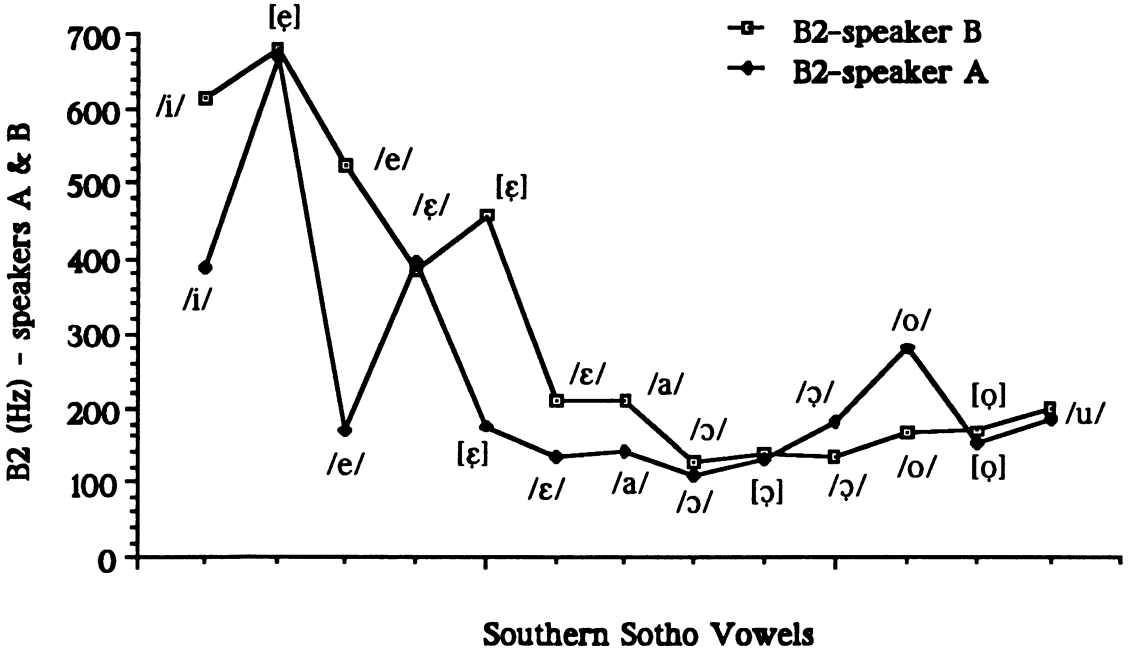

Figure 12: Mean second formant bandwidths for speakers A and B.

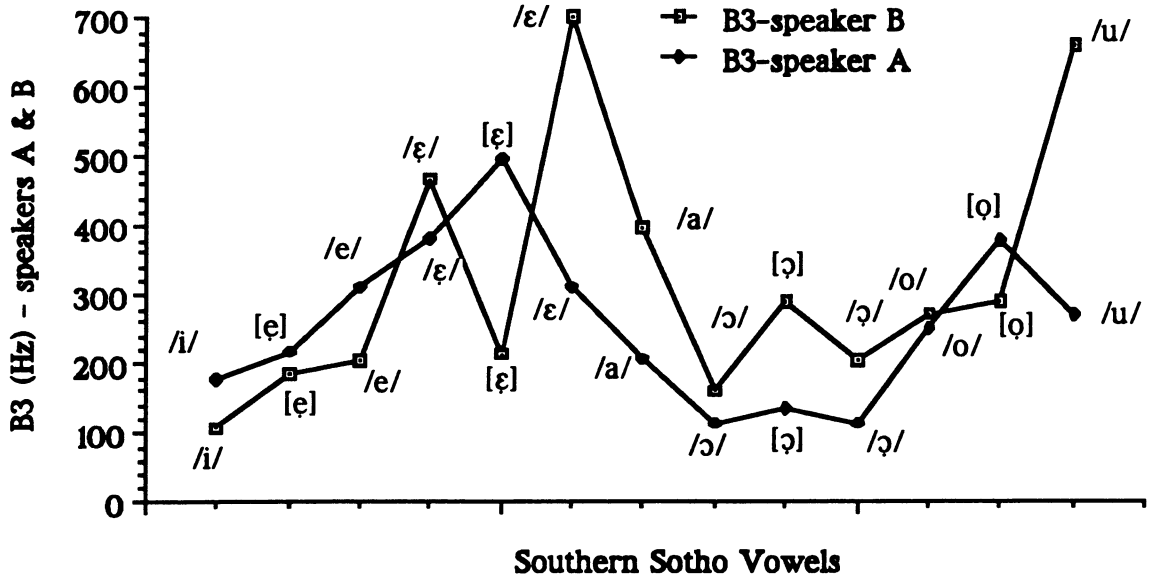

Figure 13: Mean third formant bandwidths for speakers A and B.

2.2.3. Pitch

Speaker A has a lower pitch level than speaker B in all vowels, except for the front vowel /i/, in which speaker A has a high pitch and speaker B has a low pitch. This may be due to a reading error on the part of speaker A, since the intended keyword has low tone on the target vowel. For the back vowel /u/, the two speakers have the same pitch. Refer to Figure 14 and Table 1.

The ANOVA shows a significant difference in the pitch level of the two speakers, $F(1,258)=9.972$, $p = 0.0018$.

2.2.4. Summary

These results provide an answer to the question raised earlier: "How do the differences between speakers affect formant frequency, bandwidth and/or pitch of the vowel?" We see that related to the difference in the age of the speakers is a significant difference in all the variables tested: formant frequency, bandwidth and pitch level.

It now remains to be determined whether this difference between speakers affects their realization of the vowels and/or the vowel heights. Discussion of the spectral qualities of the vowels follows in section 3.

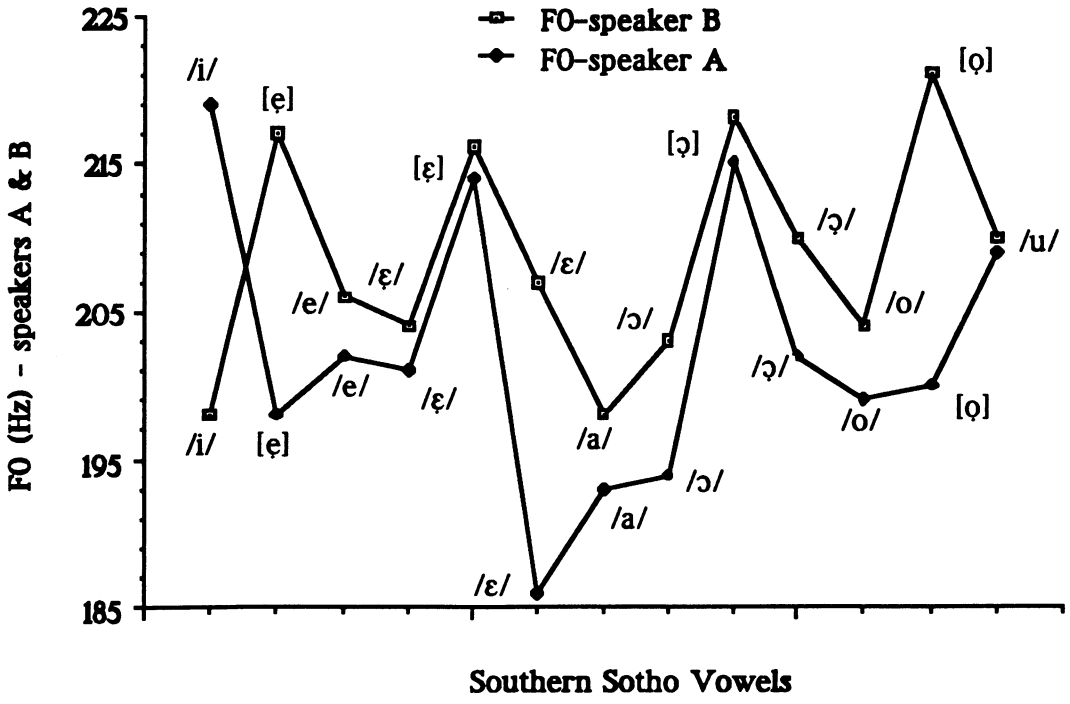

Figure 14: Mean pitch levels (FO) for speakers A and B.

3. SPECTRAL QUALITIES OF SOUTHERN SOTHO VOWELS

3.1. Individual Vowels (as distinguished by their features)

The focus of this section is on determining whether the nine phonemic vowels are distinguished acoustically from one another in formant frequency, bandwidth and/or pitch. In order to do this, individual vowels were tested independently to determine their individual frequencies, bandwidths and pitch. Measurements were taken from the first three formants on the spectrogram, i.e. F1, F2, F3. Since each vowel was repeated 10 times, there are 10 frequency measurements, 10 bandwidth measurements and 10 pitch measurements (FO) for each vowel. The results of one factor ANOVAs on each of these acoustic measures show that there are significant differences in formant frequency, bandwidth and pitch among the vowels.

F(12,117) 222.37, $p < .0001$ for F1 (speaker A);
75.639, $p < .0001$ (speaker B);

F(12,117)	164.11,	$p < .0001$ for F2 (speaker A);
	199.343,	$p < .0001$ (speaker B);
F(12,117)	5.086,	$p < .0001$ for F3 (speaker A);
	2.724,	$p = .0028$ (speaker B).
F(12,117)	17.617,	$p < .0001$ for B1 (speaker A);
	8.936,	$p < .0001$ (speaker B);
F(12,117)	9.664,	$p < .0001$ for B2 (speaker A);
	9.521,	$p < .0001$ (speaker B);
F(12,117)	5.031,	$p < .0001$ for B3 (speaker A);
	5.266,	$p = .0028$ (speaker B).
F(12,117)	4.004,	$p < .0001$ for FO (speaker A);
	3.457,	$p < .0001$ (speaker B).

In the following discussion, we will see that /ɛ̨/ and /ɔ̨/ are clearly distinguished from /ɛ/ and /ɔ/. We will be especially interested in seeing whether or not the derived vowels [ɛ̨ ɔ̨] are phonetically distinct from the unconditioned phonemes /ɛ̨ ɔ̨/.

3.2. F_1 and B_1

F1 is conversely related to the tongue height of vowels: as tongue height is higher, F1 is lower. Significant differences in F1 indicate that some of the vowels are well separated in vowel height, as illustrated by Figure 15 for speaker A, Figure 16 for speaker B, and Figure 8 comparing both speakers A and B. In Figure 8 we see a similar pattern in first formant frequencies for both speakers, i.e. high first formant for the lowest vowel /a/ and low first formant for high front /i/ and back /u/. Thus, vowel heights are distinguished acoustically in the same way for both speakers. Of particular importance is the observation that the differences in F_1 frequency between the two speakers' vowels are essentially parallel across vowels. As Table 1 shows, the low unrounded back vowel [a] has the highest F_1 frequency mean for both speakers. Furthermore, as the vowels become higher, the F_1 frequency means become lower. This is also illustrated in Figure 15 (speaker A) and Figure 16 (speaker B).

The results in Table 1 also show that there is very little difference in F_1 values between phonemic /ɐ/ as in /lɐkɐtla/ and derived [ɐ] as in [ikɐtlilɐ]; as well as between /ɔ/ as in /mokɔtla/ and [ɔ] as in [ikɔtlilɐ]. As the table shows, /ɐ/ seems to be slightly lower in frequency than [ɐ], and /ɔ/ for speaker A has a slightly lower frequency than [ɔ]. However, these differences in first formant frequency do not prove statistically significant.

Table 1

F1, B1 and FO Means of Speakers A and B for All Vowels

	Speaker	/i/	[ɐ]	/e/	/ɐ/	[ɛ]	/ɛ/	/a/	/ɔ/	[ɔ]	/ɔ/	/o/	[o]	/u/
F1	A	276	319	385	416	426	546	884	564	420	414	393	322	255
	B	283	302	422	517	542	791	986	813	568	569	465	346	261
B1	A	51	59	35	74	84	105	188	117	115	109	90	94	52
	B	88	123	104	149	167	106	34	122	205	152	178	179	84
FO	A	219	198	202	201	214	187	193	194	215	202	199	200	210
	B	198	217	206	204	216	207	198	204	218	210	204	221	210

The mean differences in first formant frequency are, for speaker A: 10 Hz for [ɐ]:/ɐ/ and just 6 Hz for [ɔ]:/ɔ/, while for speaker B: 25 Hz for [ɐ]:/ɐ/ and only 1 Hz for [ɔ]:/ɔ/. The Scheffé post hoc test for pairwise comparison shows that none of the derived phonemic pairs are significantly different from one another in first formant frequency : for speaker A: for [ɐ]:/ɐ/, $F(1,19)=.036$; for [ɔ]:/ɔ/, $F(1,19)=.015$, and for speaker B: for [ɐ]:/ɐ/, $F(1,19)=.042$; for [ɔ]:/ɔ/, $F(1,19)=.00006$; for all $p>.05$.

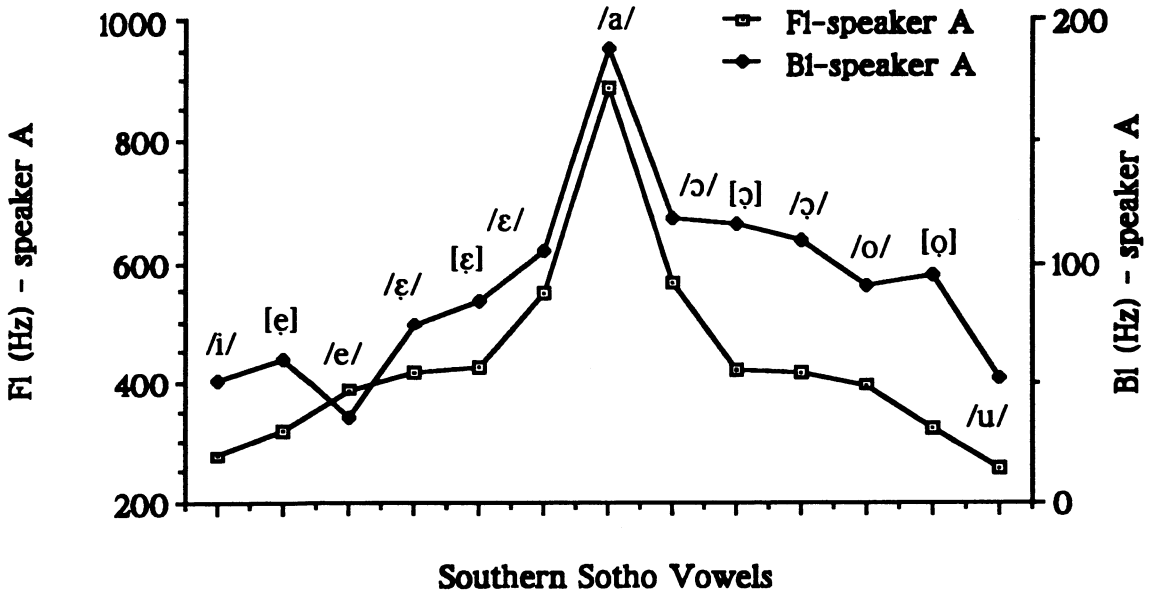

Figure 15: Mean first formant frequencies and bandwidths for speaker A; with the left axis indicating frequency and the right axis indicating bandwidth.

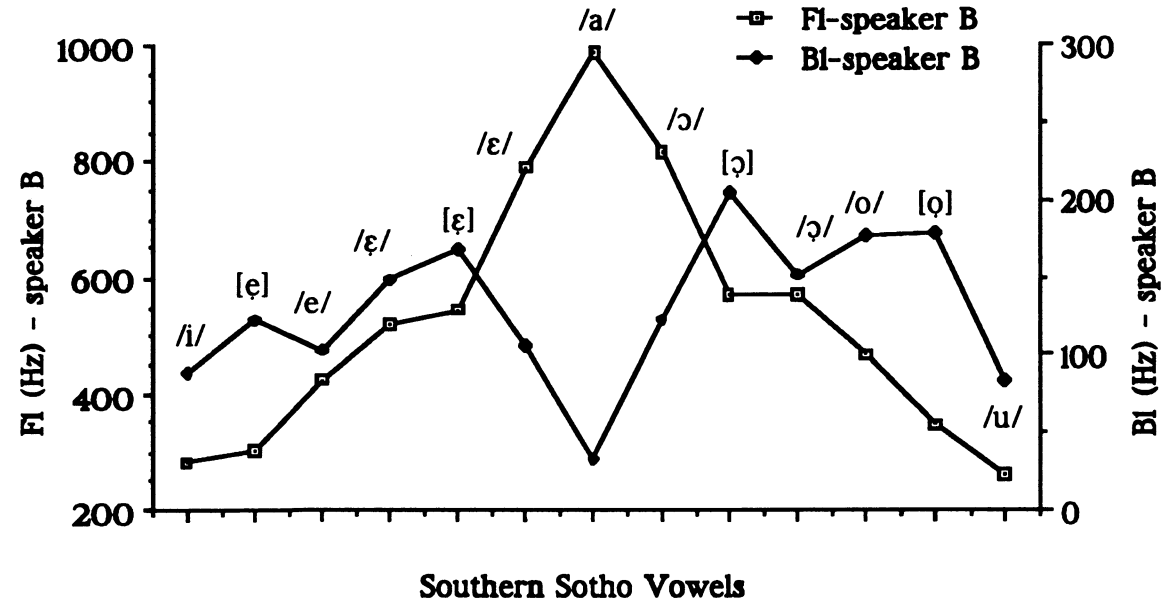

Figure 16: Mean first formant frequencies and bandwidths for speaker B; with the left axis indicating frequency and the right axis indicating bandwidth.

Table 1 also presents the difference in bandwidth among the various vowels; refer also to Figure 15 (speaker A) and Figure 16 (speaker B). The first formant bandwidth does not correlate perfectly with the height of the vowels. For the two speakers, there are some irregularities in the curves. For speaker A, /a/ has the largest bandwidth (188 Hz), and we observe a decrease in bandwidth towards the high vowels. Yet both the mid-high vowels, /e/ and /o/, with bandwidths of 35 Hz and 90 Hz, respectively, have smaller bandwidths than the higher vowels. For speaker B, /a/ has the smallest bandwidth, measuring just 34 Hz.

There is also a small but nonsignificant difference in first formant bandwidth between [ɛ̨] and /ɛ̨/ and between [ɔ̨] and /ɔ̨/. Mean differences in bandwidth for speaker A are 10 Hz for [ɛ̨]:/ɛ̨/ ($F(1,19)=.05$) and 6 Hz for [ɔ̨]:/ɔ̨/ ($F(1,19)=.017$), while for speaker B they are 18 Hz for [ɛ̨]:/ɛ̨/ ($F(1,19)=.05$) and 53 Hz for [ɔ̨]:/ɔ̨/ ($F(1,19)=.455$); all not significant at $p<.05$ in the Scheffé post hoc pairwise comparison.

3.3. F_2 and B_2

In this section, we examine the frequency and bandwidth of the second formant (F2), which is related to tongue frontness and lip rounding. We continue to pay particular attention to the vowels [ɛ̨], /ɛ̨/, [ɔ̨] and /ɔ̨/. The results appear in Table 2 and are also illustrated in graph form in Figures 17 and 18.

Table 2

F_2 and B_2 Means of Speakers A and B for All Vowels

	Speaker	/i/	[ɛ̨]	/e/	/ɛ̨/	[ɛ]	/ɛ/	/a/	/ɔ/	[ɔ̨]	/ɔ̨/	/o/	[o̜]	/u/
F_2	A	2264	2168	2426	2367	2346	2258	1645	1177	1251	974	928	1295	1016
	B	2282	2390	2413	2531	2404	2469	1969	1449	1520	1331	1309	1591	1096
B_2	A	385	667	167	397	175	134	142	107	130	181	281	153	185
	B	611	681	524	384	457	207	208	128	138	136	167	168	197

Once again, the difference between the members of each pair proves to be nonsignificant. Mean differences in second formant frequency are for speaker A: 21 Hz for [ɛ̨]:/ɛ̨/ ($F(1,19)=.008$) and 277 Hz for [ɔ̨]:/ɔ̨/ ($F(1,19) = 1.404$), while for speaker B, they are 127 Hz for [ɛ̨]:/ɛ̨/ ($F(1,19) =.478$) and 189 Hz for [ɔ̨]:/ɔ̨/ ($F(1,19)=1.053$); again all pairwise comparisons are non-significant ($p > .05$). The mean differences in bandwidth are also all not

significantly different: for speaker A, there is a difference of 222 Hz for the second formant bandwidth for [ɐ̨]:/ɐ̨/ (F(1,19)=.787) and of 51 Hz for [ɔ̨]:/ɔ̨/ (F(1,19)=.041), while for speaker B the bandwidth difference is 73 Hz for [ɐ̨]:/ɐ̨/ (F(1,19)=.054) and just 2 Hz for [ɔ̨]:/ɔ̨/ (F(1,19)=.00006).

3.4. F_3 and B_3

Table 3 shows the relationship between vowels in both frequency and bandwidth of the third formant, associated with lip rounding, for the two speakers. Refer also to Figures 19 and 20.

Table 3

F_3 and B_3 Means of Speakers A and B for All Vowels

	Speaker	/i/	[ɐ̨]	/e/	/ɐ̨/	[ɛ̨]	/ɛ/	/a/	/ɔ/	[ɔ̨]	/ɔ̨/	/o/	[ǫ]	/u/
F_3	A	3092	2797	3284	2721	2731	2965	2636	2857	2800	2771	2779	2609	2703
	B	3170	3237	3056	3197	3314	3048	2970	3334	3354	3164	3464	3197	2741
B_3	A	177	219	309	383	498	310	208	113	137	114	249	377	270
	B	106	185	203	468	214	700	397	160	288	203	273	291	657

Again, the differences between the members of the pairs [ɐ̨], /ɐ̨/ and [ɔ̨], /ɔ̨/ are not significant. Mean differences in third formant frequency are for speaker A: 10 Hz for [ɐ̨]:/ɐ̨/ (F(1,19)=.001) and 29 Hz for [ɔ̨]:/ɔ̨/ (F(1,19) =.005), while for speaker B, they are 117 Hz for [ɐ̨]:/ɐ̨/ (F(1,19)=.044) and 190 Hz for [ɔ̨]:/ɔ̨/ (F(1,19)=.116); again all differences are not significant. Similarly, all the differences in bandwidth are nonsignificant: for speaker A, the mean difference in third formant bandwidths is 115 Hz for [ɐ̨]:/ɐ̨/ (F(1,19) =.208) and 23 Hz for [ɔ̨]:/ɔ̨/ (F(1,19)=.008), while for speaker B, the bandwidth difference is 254 Hz for [ɐ̨]:/ɐ̨/ (F(1,19)=.406) and 85 Hz for [ɔ̨]:/ɔ̨/ (F(1,19)=.045).

We can, therefore, with respect to all measures of the first three formants, consider the members of the two pairs of sounds /ɐ̨/ and [ɐ̨], and [ɔ̨] and /ɔ̨/ to be sounds of the same height. This is a crucial point as we are now able to refer to a single front sound ɐ̨ and a single back sound ɔ̨. Since both the basic (/ɐ̨ ɔ̨/) and the derived ([ɐ̨ ɔ̨]) vowels have the same height, we will henceforth set aside discussion of the derived [ɐ̨ ɔ̨] height and compare only the basic /ɐ̨ ɔ̨/ with the other phonemic sounds.

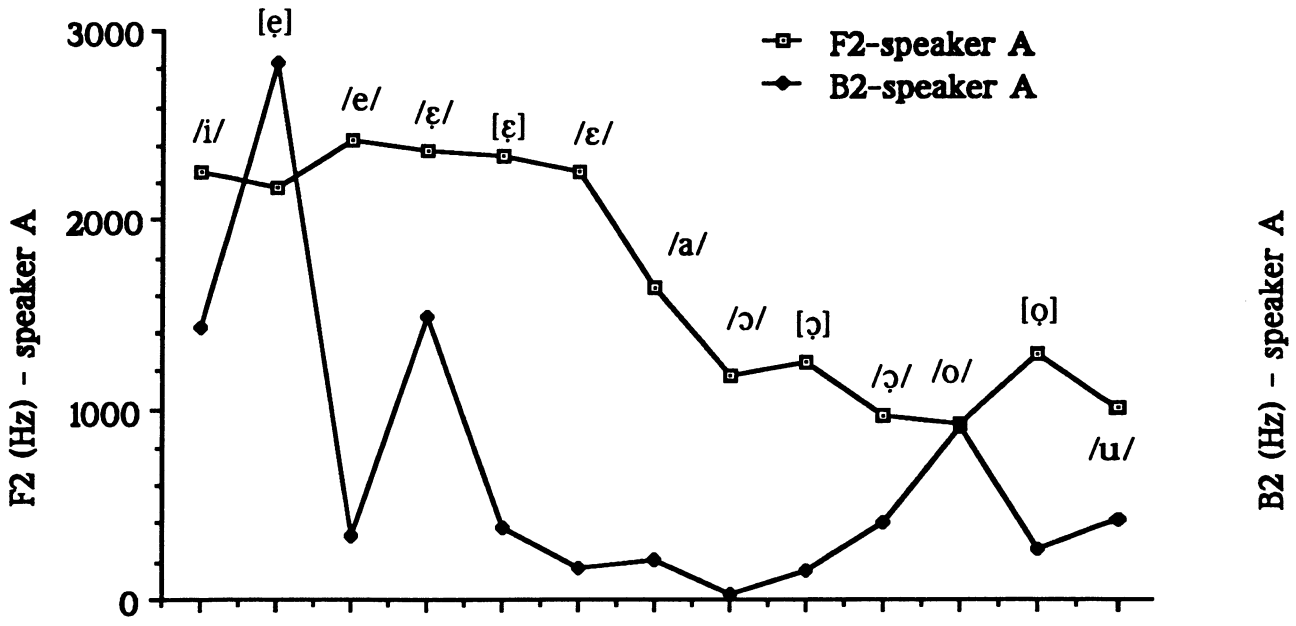

Figure 17: Mean second formant frequencies and bandwidths for speaker A; with the left axis indicating frequency and the right axis indicating bandwidth.

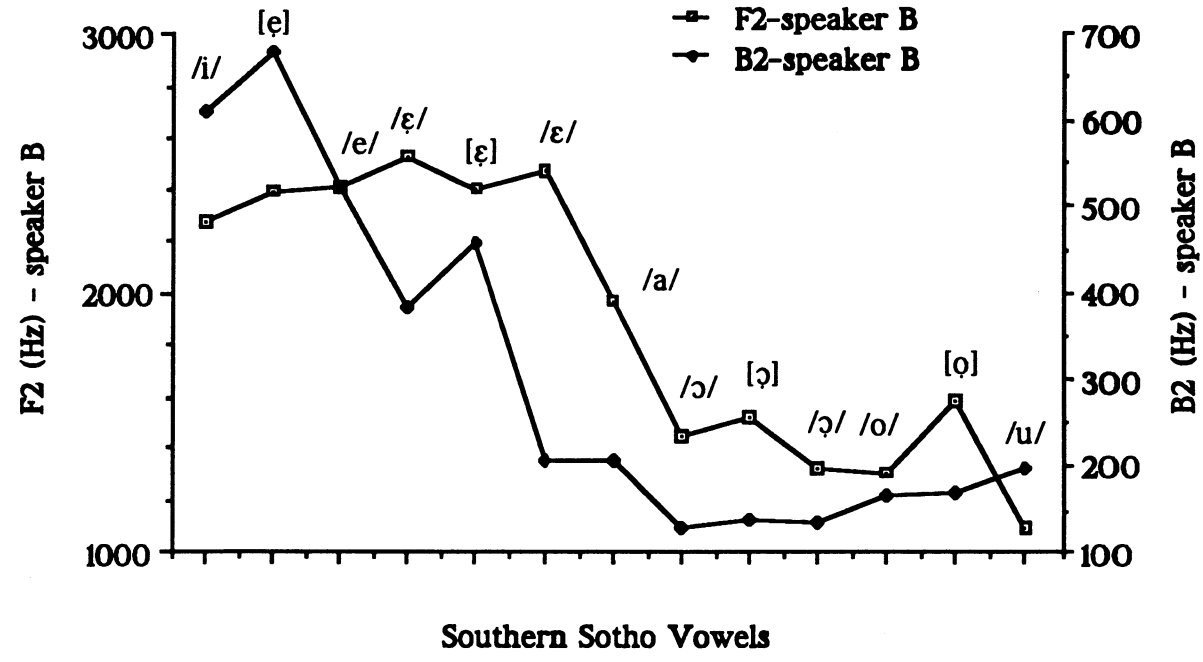

Figure 18: Mean second formant frequencies and bandwidths for speaker B; with the left axis indicating frequency and the right axis indicating bandwidth.

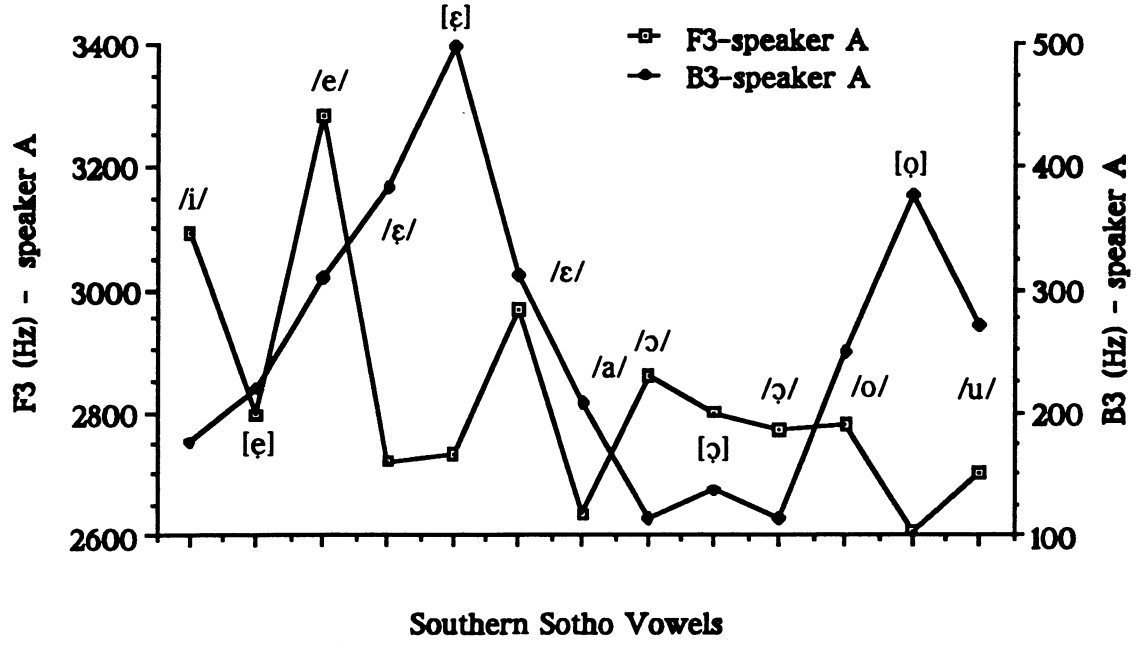

Figure 19: Mean third formant frequencies and bandwidths for speaker A; with the left axis indicating frequency and the right axis indicating bandwidth.

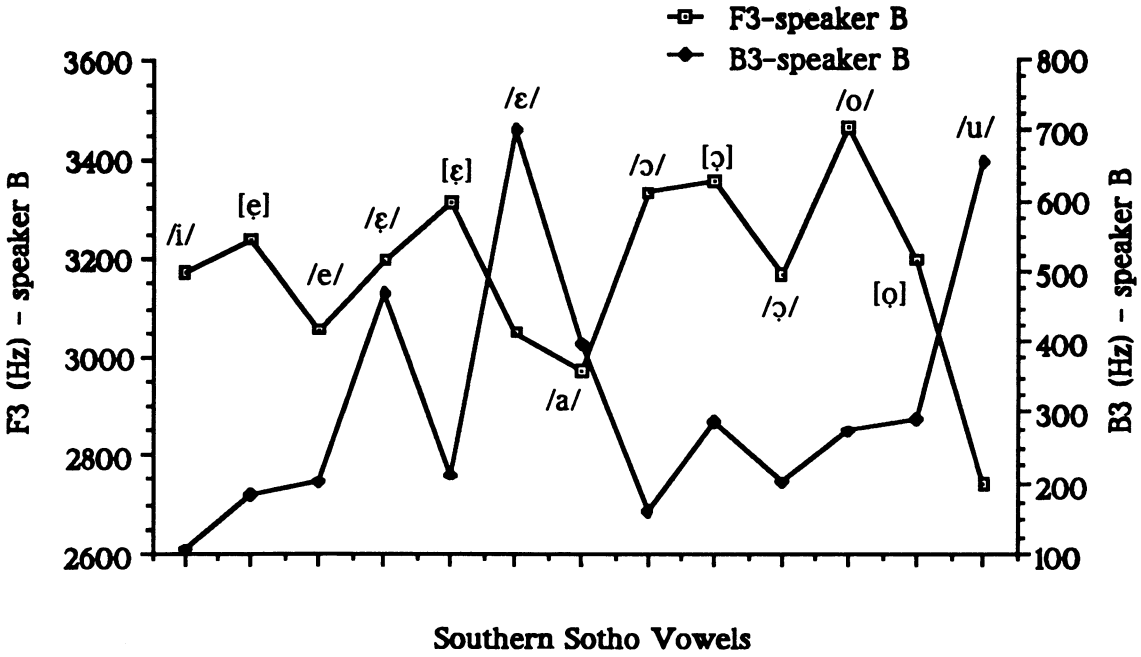

Figure 20: Mean third formant frequencies and bandwidths for speaker B; with the left axis indicating frequency and the right axis indicating bandwidth.

3.5. A Comparison of the Mid Vowels /ɛ ɐ̞ e/ and /ɔ o̞ o/

As stated earlier, it is important to look closely at the mid vowels /ɛ ɐ̞ e/ and /ɔ o̞ o/ to determine their individuality as phonemic sounds. Table 4 shows the mean frequencies of the three formants (F1, F2, F3) and pitch (FO) of these vowels for the two speakers.

Table 4

F_1, F_2, F_3 and FO Means of Speakers A and B for /e ɐ̞ ɛ/ and /o o̞ ɔ/

Speaker	Formant	Front Vowels			Back Vowels		
		e	ɐ̞	ɛ	o	o̞	ɔ
A	F1	385	416	546	393	414	564
B		422	517	791	465	569	813
A	F2	2426	2367	2258	928	974	1177
B		2413	2531	2469	1309	1331	1449
A	F3	3284	2721	2965	2779	2771	2857
B		3056	3197	3048	3464	3164	3334
A	FO	202	201	187	199	202	194
B		206	204	207	204	210	204

Table 5 presents the mean differences of F1, F2, F3 and FO for these vowels. These differences were calculated by subtracting the value of a vowel from that of the vowel next lower in height, e.g.:

Front vowels		**Back vowels**
/ɛ/ - /ɐ̞/ = x		/ɔ/ - /o̞/ = x
/ɐ̞/ - /e/ = x		/o̞/ - /o/ = x
	and/or	
[ɐ̞] - /ɐ̞/ = x		[o̞] - /o̞/ = x

For F1 the mean difference between /ɛ/ and /ɐ̞/ for the two speakers, 130 (speaker A) and 274 (speaker B), seems high enough to clearly separate the two sounds in height. This can also be said of the sounds /ɔ/ and /o̞/ which have a mean difference of 150 for speaker A and 244 for speaker B. The mean difference between /ɐ̞/ and /e/ of 31 (speaker A) and 95 (speaker B), and between /o̞/ and /o/ of 21 (speaker A) and 104 (speaker B) are not as high, however. The differences do, nonetheless, indicate a difference in height between these vowels.

Table 5				
F_1, F_2, F_3 and FO Mean Differences for /e ɛ̨ ɛ/ and /o ɔ̨ ɔ/				
	Speakers		Speakers	
	A	B	A	B
F1	ɛ - ɛ̨ = 130	274	ɔ - ɔ̨ = 150	244
	ɛ̨ - e = 31	95	ɔ̨ - o = 21	104
F2	ɛ - ɛ̨ = -109	- 62	ɔ - ɔ̨ = 203	118
	ɛ̨ - e = - 59	118	ɔ̨ - o = 46	22
F3	ɛ - ɛ̨ = 244	- 149	ɔ - ɔ̨ = 86	170
	ɛ̨ - e = 563	141	ɔ - o = - 8	- 300
FO	ɛ - ɛ̨ = -14	3	ɔ - ɔ̨ = - 8	- 6
	ɛ̨ - e = - 1	- 2	ɔ̨ - o = 3	6

Scattergrams were also made in which the mean frequencies of the first formant of all vowels were plotted against the mean frequencies of the second formant, for both speakers (Figures 21 and 22). Figure 21 shows the spread of vowels for speaker A. As can be seen, the two lowest vowels, /ɛ/ and /ɔ/, are well separated from the higher vowels; [ɛ̨] and /ɛ̨/ as well as [ɔ̨] and /ɔ̨/ overlap at least in F1; and there is some overlap of these pairs with the higher vowels, /e/ and /o/, respectively, especially for the back vowels (these pairs do not overlap with raised [ẹ] and [ọ], however).

Examination of the second formant of the back vowels shows that there is more fronting in the derived sounds than in the underived sounds. The [ɔ̨] in [likɔ̨tlilɛ̨] has a higher F2 frequency than /ɔ̨/ in [mokɔ̨tla]; the [ọ] in [ikhọɬilɛ̨] also has a higher F2 frequency than the [o] in [mokota]. These changes are in addition to vowel raising (section 4), and represent an independent effect of the conditioning vowel /i/. Sounds followed by a higher sound /i/ have a higher second formant frequency, e.g. [ikɔ̨tlilɛ̨], [ikhọɬilɛ̨]. This indicates that they are articulated further forward than those not followed by a higher sound, e.g. /mokɔ̨tla/.

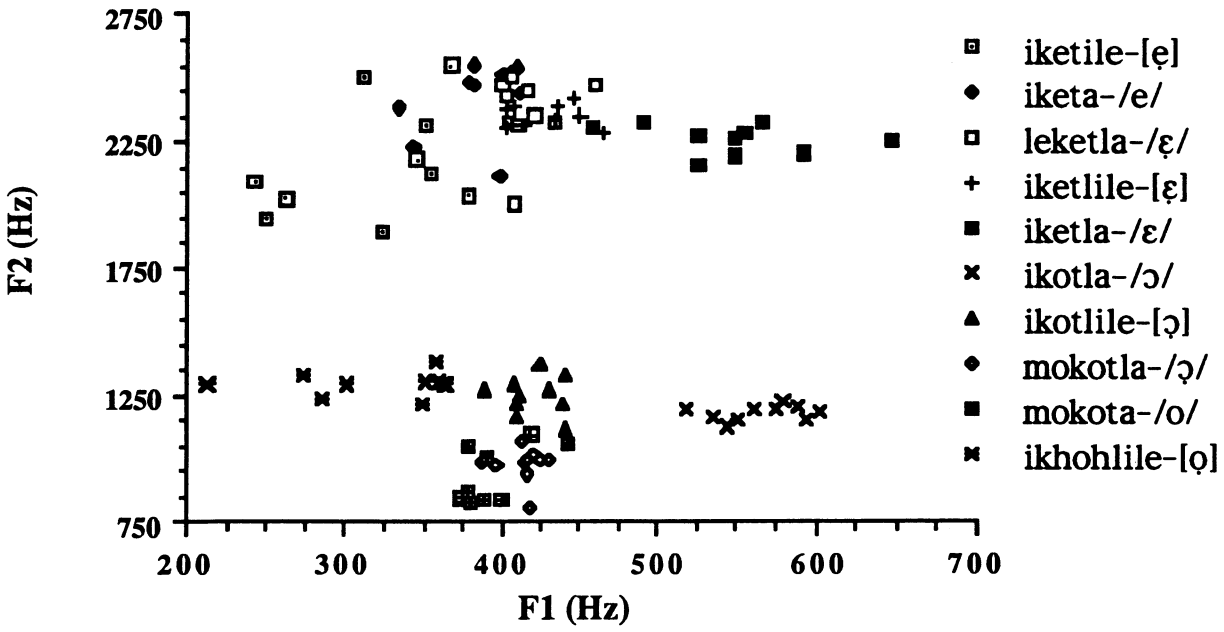

Figure 21: Speaker A: Scattergram of formant 1 by formant 2 frequencies showing how vowels are related according to the frequencies of these two formants.

Figure 22 shows the spread of each vowel with its 10 repetitions for speaker B. As with speaker A, the two lowest vowels /ɛ/ and /ɔ/ are well separated from the higher vowels, but there is substantial overlap between [ɛ̣] and /ɛ̣/ as well as between [ọ] and /ɔ̣/, with less overlap between each of these pairs of vowels and the higher vowel /e/ and /o/, respectively. Again, the overlap between the back vowels [ọ], /ɔ̣/, and /o/ is more extensive than that between the front vowels [ɛ̣], /ɛ̣/ and /e/. Once again we see the fronting effect of /i/ on back vowels. What is surprising with the two speakers is the behavior of [ẹ] in [ikẹtilɛ̣], whose second formant frequency spreads from high to low.

Mean F1 was plotted against mean F2, overlaid with the standard deviation of both F1 and F2. This is shown in Figure 23 (speaker A) and Figure 25 (speaker B). F1 was also plotted against the average mean of F2 and F3, overlaid with the standard deviation of F1 and the average mean of F2 and F3. Refer to Figure 24 (speaker A) and Figure 26 (speaker B).

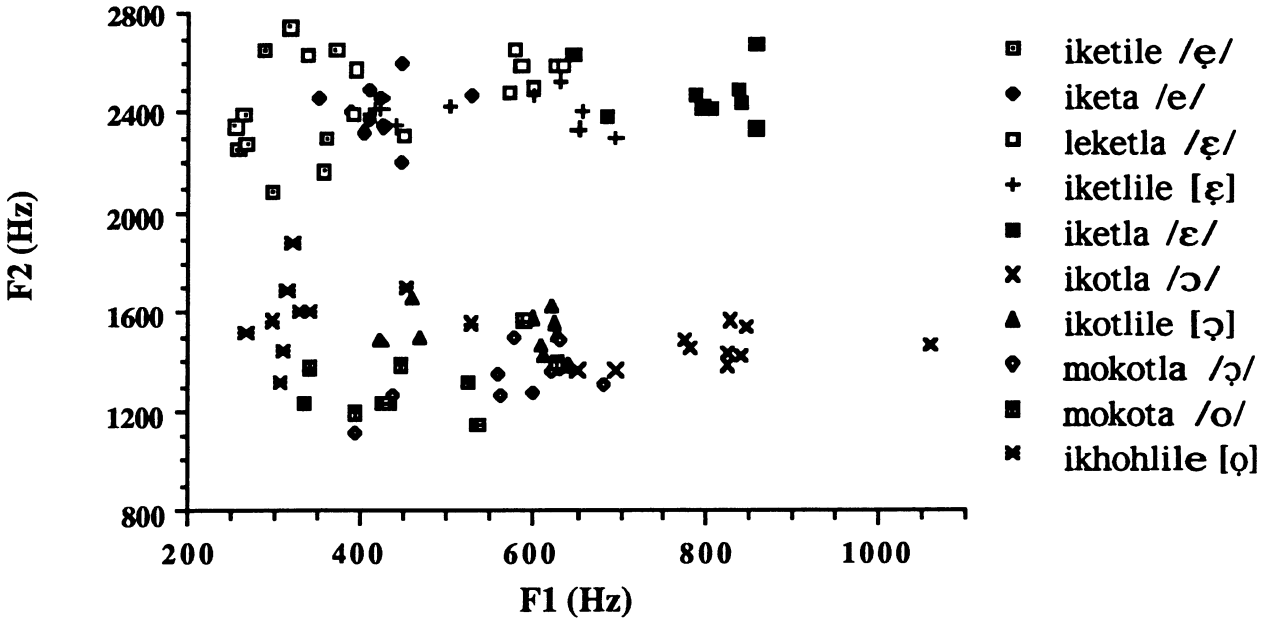

Figure 22: Speaker B: Scattergram for F1 by F2 frequencies showing all vowels.

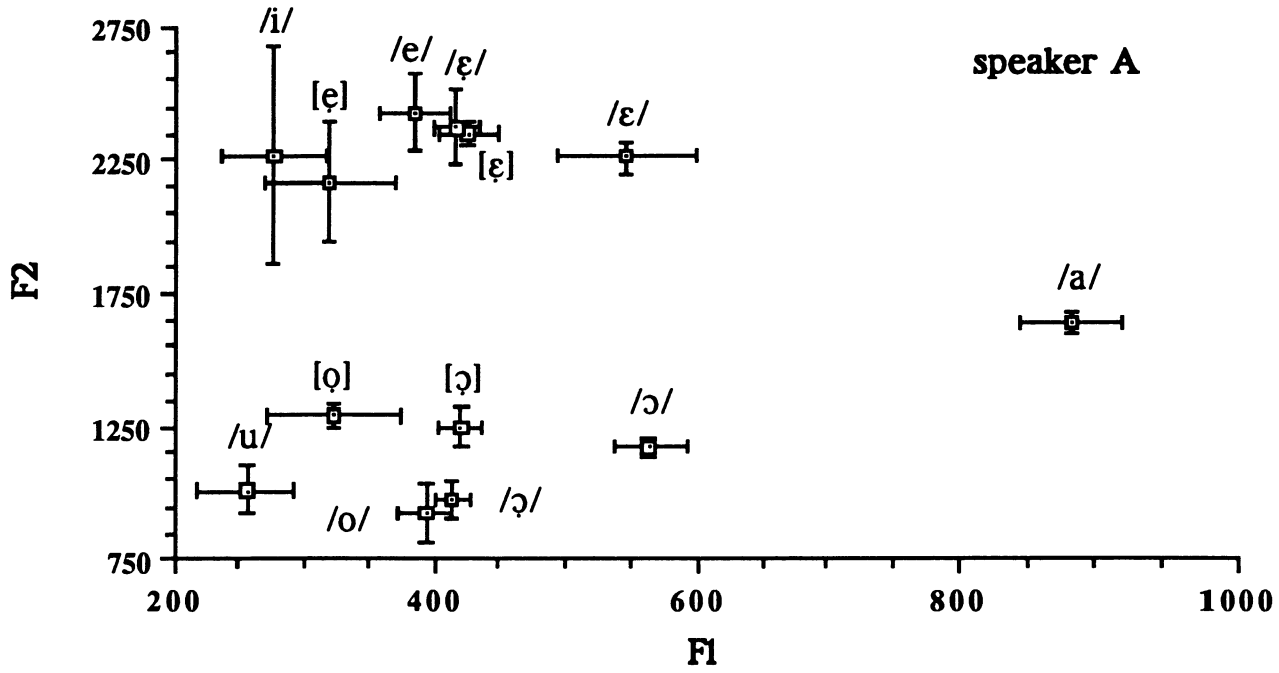

Figure 23: Speaker A: Mean frequency of F1 by mean frequency of F2, overlaid with the standard deviations.

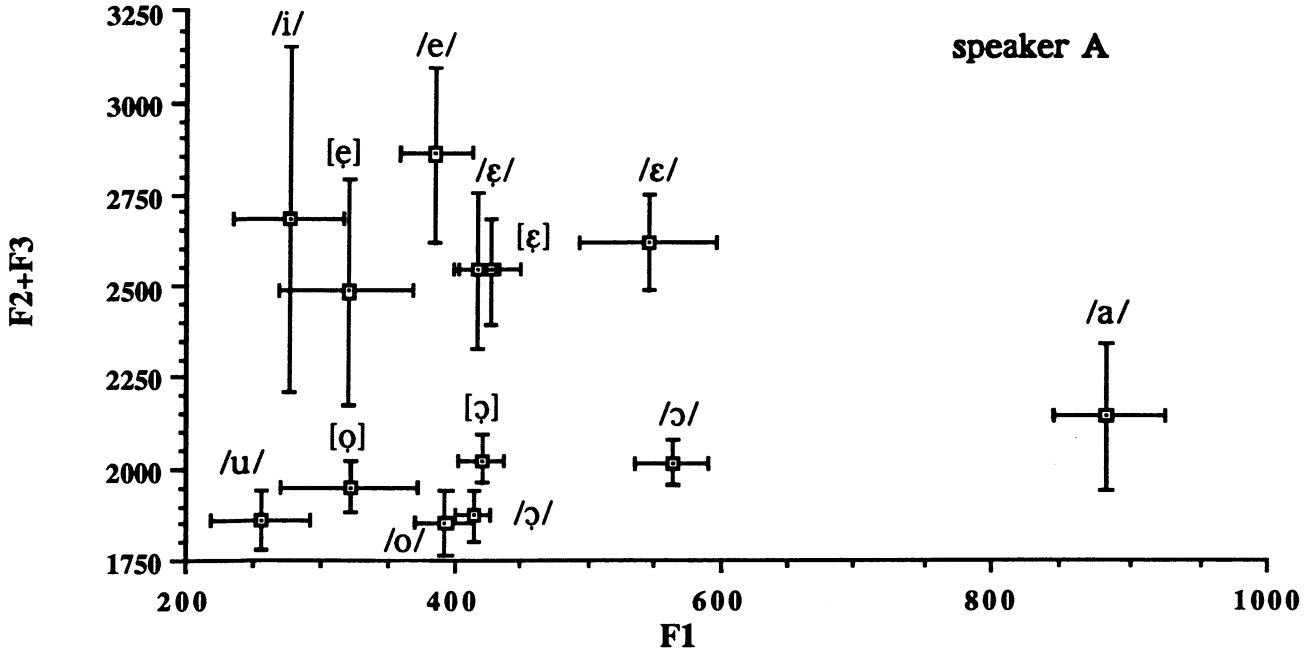

Figure 24: Speaker A: Mean frequency of F1 by mean frequency of F2 + F3, overlaid with standard deviations.

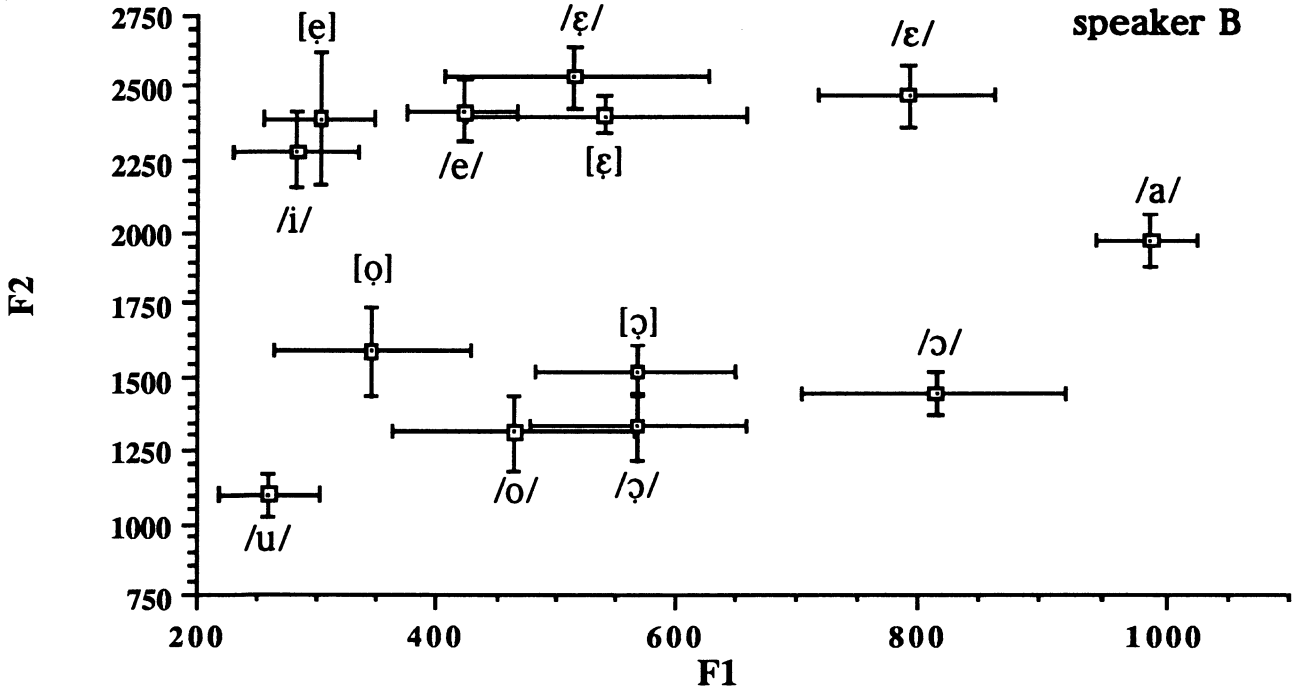

Figure 25: Speaker B: Mean F1 vs. F2 frequency, overlaid with standard deviations.

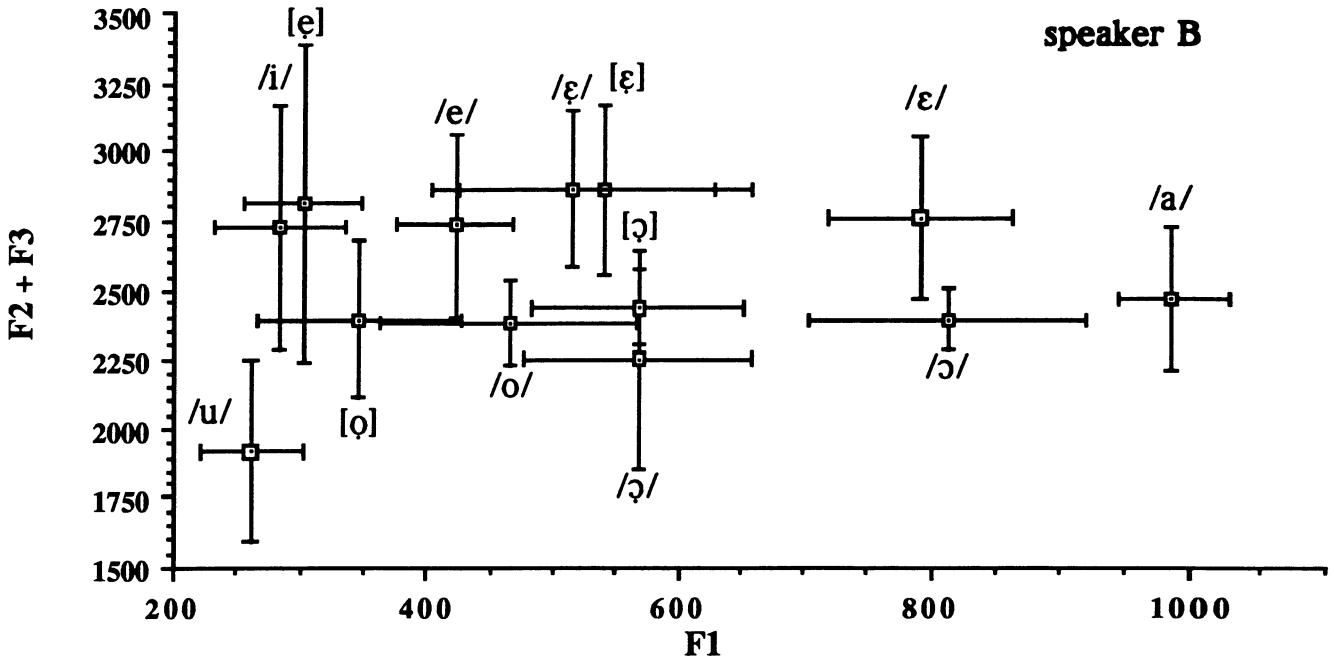

Figure 26: Speaker B: Mean F1 frequency by the average mean F2 and F3 frequency, overlaid with standard deviations.

3.6. Conclusion

Differences in the spectral qualities of the vowels suggests that the nine Southern Sotho vowels are distinguished acoustically on the basis of differences in F1 and F2 frequency and bandwidth. This then makes five phonemic heights, as shown earlier in the analysis presented in Figure 6. Differences in vowel height are reflected in corresponding spectral differences among the vowels in the speech of both speakers.

In addition, we have seen that the derived vowels [ɛ ɔ] are not phonetically distinct from the unconditioned phonemes /ɛ ɔ/, showing that Vowel Raising is a neutralizing rule.

4. VOWEL FEATURES

4.1. Feature Analysis: the Problem

So far we have seen that Southern Sotho has nine phonemic vowels and eleven phonetic ones. Figure 8 above shows how first formant frequencies separate the nine phonemic vowels according to their height in a similar way for both speakers. Distinctive features allow us to group

together sounds that belong to the same natural class. In English, for example, the vowels illustrated in the words below can be distinguished from one another using the vowel features as shown in Table 6:

Front		Back	
/i/	heed	/u/	who'd
/ɪ/	hid	/ʊ/	hood
/e/	hayed	/o/	hoed
/ɛ/	head	/ɔ/	hawed
/æ/	had	/a/	hod

Table 6: English vowels

	Front vowels					Back vowels				
	i	ɪ	e	ɛ	æ	a	ɔ	o	ʊ	u
high	+	+	-	-	-	-	-	-	+	+
low	-	-	-	-	+	+	-	-	-	-
tense	+	-	+	-	-	-	-	+	-	+
back	-	-	-	-	-	+	+	+	+	+
round	-	-	-	-	-	-	+	+	+	+

These vowel features (taken from Chomsky & Halle 1968) include two which refer to vowel height, i.e. [high] and [low]. At most three heights can be distinguished by these two features, since the specification [+ high, + low] is an impossible fourth combination. As Keating (1987) indicates, the need to distinguish at least four phonetic heights occurs again and again in discussion of vowel contrasts.

The acoustic measurements and examples in the discussion above have proven that in Southern Sotho there is need to distinguish not just four but five heights. The vowel chart for nine phonemic vowels in Figure 6 indicates five phonemic heights in which each vowel is paired with another at the same height except for /a/, which stands alone as the lowest sound. The pairs stand according to these phonemic heights as follows:

Heights	Front Vowels	Back Vowels
1	/i/	/u/
2	/e/	/o/
3	/ɛ̣/	/ɔ̣/
4	/ɛ/	/ɔ/
5		/a/

For the eleven phonetic vowels, the number of heights increases to six, composed of the pairs arranged as follows:

Heights	Front Vowels	Back Vowels
1	[i]	[u]
2	[ẹ]	[ọ]
3	[e]	[o]
4	[ɛ̣]	[ɔ̣]
5	[ɛ]	[ɔ]
6		[a]

The extra height (level 2) is obtained from the process of vowel raising as will be discussed further below.

The vowel features that appear in Table 7 were used in the acoustic analysis of Southern Sotho vowels. Anticipating our later discussion, the feature labeled e̲ stands for Lindau's proposed feature [Expanded] (Lindau 1975) and is used provisionally as a means of giving each vowel a distinct feature specification.

Table 7: Southern Sotho Vowels

	Front vowels					Back vowels					
	i	[ẹ]	e	ɛ̣	ɛ	a	ɔ	ɔ̣	o	[ọ]	u
high	+	-	-	-	-	-	-	-	-	-	+
low	-	-	-	+	+	+	+	+	-	-	-
e	+	+	-	+	-	-	-	+	-	+	+
back	-	-	-	-	-	+	+	+	+	+	+
round	-	-	-	-	-	-	+	+	+	+	+

4.2. Vowel Raising

In Southern Sotho, a process of partial height assimilation takes place when certain vowels are followed in the word by higher vowels. In other words, vowels of lower heights shift toward vowels of higher heights. This does not, however, result in complete assimilation because lower vowels do not change completely to the height of the sounds that influence them. The shift is only from their original height to the one immediately above it. We can formulate this rule of **Vowel Raising** as follows: *high sounds cause the assimilation of lower sounds that precede them.* This rule, which affects the vowels /e, o, ɛ, ɔ/, is presented below in formal notation:

/e o/ → [ẹ ọ] /__ /i u/

/ɛ ɔ/ → [ɛ̣ ɔ̣] /__ /i u/ /e o/ /ɲ ŋ ts/ [3]

The first rule states that /e/ or /o/ change to [ẹ] or [ọ] respectively when each is followed by either /i/ or /u/. By the second rule, /ɛ/ or /ɔ/ change to [ɛ̣] or [ɔ̣] respectively when followed by either /i/, /u/, /e/, /o/, /ɲ/, /ŋ/ or /ts/. These changes are illustrated in the following examples:

/e/ → [ẹ] / __ /i/ molẹmi (cultivator)		cf. lema (cultivate)
__ /u/ lẹfuwɛ̣ (has been paid)		cf. lefa (pay)
/o/ → [ọ] / __ /i/ ditọkisɔ (corrections)		cf. loka (be right)
__ /u/ nọkuwɛ̣ (has been seasoned)		cf. noka(season)
/ɛ/ → [ɛ̣] / __/i/ mosɛ̣bi (gossiper)		cf. seba (gossip)
__/u/ bɛ̣tluwɛ̣ (has been sharpened)		cf. bɛtla (sharpen)
__/e/ so bɛ̣tle (not to sharpen)		cf. bɛtla (-sharpen)
__/o/ ɛ̣polla (dig out)		cf. ɛpa (-dig)
__/ɲ/ kɛ̣ɲa (insert)		cf. kɛna (enter)
__/ŋ/ kɛ̣ŋŋwa (be inserted)		cf. kɛna (enter)
__/ts/ ɛ̣tsa (do)		cf. ɛta (visit)
/ɔ/ →[ɔ̣] / __/i/ serɔ̣ki (poet)		cf. rɔka (praise)
__/u/ sebɔ̣du (a rotten thing)		cf. bɔla (rot)
__/e/ bɔ̣ne (have seen)		cf. bɔna (see)
__/o/ kɔ̣bolla (unbend)		cf. kɔba (bend)
__/ɲ/ bɔ̣ɲa (smile)		cf. bɔna (see)
__/ŋ/ ŋkɔ̣ŋ (on the nose)		cf. ŋkɔ (nose)
__/ts/ ŋɔ̣tse (has written)		cf. ŋɔla (write)

Using the vowel features in Table 7, these rules are reformulated as follows:

Rule 1[4]

$$\begin{array}{lcll} V & & & \\ \alpha \text{ back} & \rightarrow & [+e]/ \_\_ & +e \\ \alpha \text{ round} & & & +high \end{array}$$

Rule 2

$$\begin{array}{lcll} V & & & \\ +\text{low} & & & \\ \alpha \text{ back} & \rightarrow & [+e]/ \_\_ & [-low] \\ \alpha \text{ round} & & & \end{array}$$

Rule 1 requires that a front unrounded vowel, e.g. /e ɛ/, or a back rounded vowel, e.g. /o ɔ/, acquires the property [+e], i.e. becomes higher, when followed by another vowel that has the property [+e], and is high (/i/ or /u/). Rule 2 states that a vowel which is low and either a front unrounded vowel, e.g. /ɛ/, or a back rounded vowel, e.g. /ɔ/, acquires the property [+e], i.e. becomes higher, when it is followed by a nonlow vowel, e.g. /i u e o/.

4.3. Feature Analysis: a Proposal

It is clear that the two SPE vowel features [high, low] are not sufficient to distinguish the five vowel heights in Southern Sotho. The question still remains as to which features are suitable for this kind of vowel height inventory. An additional vowel feature is needed, which we have tentatively termed e̲, that will characterize the /ɛ̣ ɔ̣/ height as a primary height in this continuum of height values distinct from the others.

It would be appropriate to consider our results in the light of Lindau's findings (1975) for other African languages. Lindau proposes a vowel feature [Expanded], referring to the size of the pharynx, as part of a universal set of features to describe vowel harmony. In some languages she has discovered a division of vowels into two sets, distinguished by the relative size of the pharynx. For example, in the Akyem dialect of Akan, there are ten vowels distributed into two sets as follows:

Set 1		**Set 2**	
i	u	ɪ	ʊ
e	o	ɛ	ɔ
ə		a	

Lindau finds that Set 1 vowels are [+Expanded], meaning that the pharynx is expanded by advancing the tongue root and lowering the larynx. Conversely, Set 2 vowels are [-Expanded], indicating that the pharynx is contracted by adopting a neutral or retracted tongue root and, in most cases, raising the larynx.

We suggest that in Southern Sotho Vowel Raising, the feature [Expanded] may also account for the relationship between higher sounds and lower sounds, as shown in our feature chart above. Following Lindau's analysis, [-Expanded] vowels may become [+Expanded] under the conditions stated in the two rules. This analysis has the advantage of treating at least the first of the rules as assimilatory, though it provides a less natural account of the second. As we have no articulatory data at our disposal, we must leave this hypothesis for further study.

NOTES

1. The diacritic mark ´ is used to mark high tone. Unmarked vowels have low and/or mid tone.
2. h = high, l = low, b = back, r = round, e = a property given temporarily for analysis, referring to Lindau's feature [Expanded]; d = derived (given temporarily for analysis and meaning that the vowel is higher because a high vowel follows in the next syllable).
3. /ɲ ŋ ts/ are consonants that have shifted in the context of a following historical high front vowel *i̯, and, therefore, still show the influence of that high front vowel.
4. V = vowel; α = either + or -, depending on the particular vowel mentioned at a time; the fact that both [back] and [round] have the value α indicates that the two features must have the same value. This prevents the second rule from applying to /a/ in which [back] and [round] do not have the same value.

APPENDIX

Further examples of the contrast between /ɛ̨/ and /ɛ/, /ɔ̨/ and /ɔ/:

/ɛ̨/ vs. /ɛ/

(a) Nouns:

thɛ́pɛ̨ (kind of vegetable)	vs	thébɛ (shield)
pɛ́rɛ̨ (pear)	vs	pérɛ (horse)
sebɛ́lɛ̨ (rumor)	vs	lebɛlɛ́ (corn)
kwɛ̨kwɛ̨́ (kind of bird)	vs	lekxhwɛkxhwɛ (measles)
kwɛ̨na (crocodile)	vs	lekwɛba (foam)

(b) Verbs:

hɛ̨tla (look back)	vs	bɛtla (sharpen)
phɛ̨́tla (open (book))	vs	pétla (to be bright (for eyes))
lɛ̨kɛ̨́tla (-hang)	vs	kɛkɛtla (cut off (hair))

(c) Moods and Tenses:

mphílɛ̨ (has given me)	vs	mphíélɛ (sweep me off)
áhílɛ̨ (has built)	vs	á ílɛ (that he avoids)
hó jówɛ̨ ((it) has been eaten)	vs	hó jówɛ ((let) there be eaten)

/ɔ̨/ vs. /ɔ/

(d) Nouns:

mokɔ̨́tla (a sack)	vs	ŋkɔ́tla (hit me)
lekɔ̨́pɔ̨kɔ̨́pɔ̨ (big can)	vs	lekɔpɔ (forehead)
mokɔ̨́lɔ̨́kɔ̨ (procession)	vs	mokɔ́lɔ́bɔ (state of being wet)
motɔ̨́pɔ̨́tla (hard-faced person)	vs	tɔ́pátɔpa (darn a little)
kúlɔ̨ (bullet)	vs	pulɔ (reopening)
pílɔ̨ (soot)	vs	kilɔ (avoidance)
setúlɔ̨ (chair)	vs	setumɔ (fame)

(e) Pronouns:

Demonstrative:		Absolute
bɔ̨na (this one)	vs	bɔná (it)
hɔ̨na (this one)	vs	hɔná (it)
hɔ̨́łɛ̨ (all over)	vs	kxhɔłɛla (fit in well)

(f) Others:

lehákwɛ̨ (kind of stone)	vs	lé hákwɛ (that it be hung)
bohómɛ̨ (kind of plant)	vs	mó lómɛ (bit him)

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