THE ACOUSTIC CORRELATES OF ATR HARMONY IN SEVEN- AND NINE-VOWEL AFRICAN LANGUAGES: A PHONETIC INQUIRY INTO PHONOLOGICAL STRUCTURE

by

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DEDICATION

To Dad who told me I could become whatever I set my mind to

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Where does one begin to acknowledge those who have walked alongside one on a long and often lonely journey to the completion of a dissertation? My journey begins more than ten years ago while at a “paper writing” workshop in Ouagadougou, Burkina Faso. I was consulting with Rod Casali on a paper about Ikposo [ATR] harmony when I casually mentioned my desire to do an advanced degree in missiology. Rod in his calm and gentle way asked, “Have you ever considered a Ph.D. in linguistics?” I was stunned, but quickly recoverd with a quip: “Linguistics!? That’s for smart people!” Rod reassured me that I had what it takes to be a linguist. And so I am grateful for those, like Rod, who have seen in me things that I could not see for myself and helped to draw them out.

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ABSTRACT

THE ACOUSTIC CORRELATES OF ATR HARMONY IN SEVEN- AND NINE-VOWEL AFRICAN LANGUAGES: A PHONETIC INQUIRY INTO PHONOLOGICAL STRUCTURE

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This study compares eleven Niger-Congo languages with [ATR] harmony and seeks to determine especially whether the acoustic properties of the "voice quality" differences associated with [ATR] in nine-vowel languages, such as Akan, are present or absent in all, some or none of the seven-vowel languages.

Of particular interest is the nature of the height 2 and 3 vowels of the nine- and degree 2 vowels of seven-vowel systems. First, this study corroborates previous work on nine-vowel systems by demonstrating that height 2 vowels [-ATR] [ɪ ʊ] frequently overlap with height 3 vowels [+ATR] [e o]. Next, it considers the question that the two

types of seven-vowel systems recognized in African languages – /i e ɛ a ɔ o u/ and /i ɪ ɛ a ɔ ʊ u/ – may be manifestations of a single system. Given that degree 2 vowels of either seven-vowel system (/e o/ or /ɪ ʊ/) overlap in nine-vowel languages, how can we know which system we have? Do the acoustic correlates of [ATR] in nine-vowel systems help us to answer this question or is it reasonable for linguists to use indeterminacy as an argument for new theories of vowel features?

Results confirm that F1 is the primary acoustic correlate of [ATR] in both nine and seven vowel systems: [+ATR] vowels have lower F1 mean values than their [-ATR] counterparts. Other acoustic correlates of [ATR], such as bandwidth or "Normalized A1-A2," have some value in understanding the acoustics of systems with [ATR] harmony. Center of gravity, another measure of spectral flatness, also shows promise: [-ATR] vowels have higher center of gravities than their [+ATR] counterparts. Evidence suggests the extreme ends of the center of gravity measures may be more perceptually salient than those in the middle. Speakers of languages with nine underlying or surface vowels tend to exploit center of gravity extremes for one of the [ATR] pairs, but speakers of 7-vowel languages tend to have more neutral center of gravity settings. The latter finding leaves open the door that some speakers of 7-vowel languages may not be manipulating tongue root position in differentiating [ATR] harmony pairs.

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CHAPTER 1

INTRODUCTION

Phonologists have assumed either implicitly or explicitly that there are two types of seven-vowel systems in African languages: a more common one containing /i e ɛ ɑ ɔ o u/, and a less common one consisting of /i ɪ ɛ ɑ ɔ ʊ u/.[1] Archangeli and Pulleyblank (1994), for example, give examples of both types of systems: Yoruba (Defoid), many of the Edoid languages such as Edo, Okpẹ, or Ukue, or Ngbaka (Ugbangi) with the more common system, and Kinande (Bantu J) with the less common system. Hyman (1999) also mentions several Bantu languages with the more common system, including Duala (A.24), Kande (B.32), Mongo (C.6) and Lingala (C.36d). The less common system, however, has also been attested in many Bantu languages (Londo (A.11), Bira (D.32), Kikuyu (E.51) and Kimatuumbi (P.10), among others) and has been posited by some (Meeussen 1967, 1980[1969] and Guthrie 1967-71) as the system that existed in proto-Bantu.[2]

However, others, such as Hyman (1999), raise the question whether it is even possible to tell the difference between the mid vowel /e/ of the first system and the

[1] Bantuists tend to represent the highest vowels (degree 1), of the latter vowel system common in Bantu languages with a cedilla. For the purposes of clarity and consistency, I adopt the IPA system for representing Bantu throughout this work.
[2] Stewart, however, presented a paper at the 28th Colloquium on African Languages in Leiden in 1998 where he gave evidence for at least five oral vowels in Proto-Bantu *i *ɪ *a *ʊ *u.

lower high vowel /ɪ/ of the second system since they supposedly occupy acoustic space very close to one another. Assuming a categorical difference between the two types of seven-vowel systems, when encountering any given seven-vowel language how do we know which system we are faced with? Should the second highest vowels be regarded as “height two,” /ɪ/ and /ʊ/, or as “height three,” /e/ and /o/?

In some languages (e.g. Kinande (J.42)) there may be clear phonological evidence, such as allophonic variation (for example, stem vowels ɛ, ɔ → e, o before the [+ATR] agentive suffix *–i*) to decide the issue. But in the absence of such evidence, acoustic data may play an important role. When considering whether a vowel might be better categorized as height two or height three, chief among the acoustic parameters to consider is the magnitude of the first formant (F1), the clearest correlate to vowel height. As shall be demonstrated, however, for some languages, F1 is not sufficient. Other correlates, in addition to vowel formant measurements, help provide a clue to solving this puzzle: more specifically, it will be argued that there are other relevant acoustic factors to consider, including spectral measurements used for nine-vowel languages where voice quality differences have been reported, as well as center of gravity measurements.

Nine- or ten-vowel systems found in West Africa, as well as other parts of Africa, typically display a vowel harmony system based on the feature advanced tongue root [ATR], a feature whose purpose most have believed is to expand or constrict the pharyngeal cavity by advancing or retracting the root of the tongue. Among the most notable studies of languages of [ATR] harmony are Lindau 1975, Hess 1992, Tiede 1996 for Akan, Lindau 1976, which considers Akan and Ateso, and Lindau-Webb 1987, which compares Akan and Luo. These studies point out that in any given word root, all the vowels are generally characterized with an expanded (with or without a lowered larynx) or constricted pharyngeal cavity. This phenomenon has often been described as being accompanied by voice quality differences emanating either from the pharyngeal cavity or the larynx. Various impressionistic labels have been used to describe these differences: "breathy," "dull," "deep" or "hollow" for [+ATR] vowels and "bright," "tight," "creaky" or "choked" for the [-ATR] counterparts. While such voice quality differences are most noticeable in Nilo-Saharan languages (e.g. Nuer and Dinka: Welmers 1972 and Dho-Luo: Jacobson 1978), there have also been reports of such voice quality differences for some West African Niger-Congo languages (e.g. Ahanta: Berry 1955; Akan: Berry 1952, as cited in Stewart 1967; Jacobson 1978).

Others, such as Local and Lodge (1996) and Steriade (1995) suggest that apart from expanded and constricted, there may in fact be a third pharyngeal position, "neutral." Local and Lodge (1996) summarize Ladefoged (1971, 1972) as having proposed the feature [wide] as early as 1971, which would cover three states of the pharynx: wide ([+ATR]), narrow ([-ATR]), and neutral, where the tongue is in its 'normal' position, which may or may not be [-ATR]. Steriade (1995) also hypothesizes that either the [+ATR] or [-ATR] vowels in some languages actually involve a neutral tongue root position. This would mean that for some languages, a contrast between advanced tongue root position for [+ATR] vowels would contrast with a more or less neutral position for the [-ATR] vowels, while in other languages, a retracted tongue root position in the [-ATR] vowels would contrast with a more or less neutral position for the [+ATR] vowels.

Such a position is problematic, at least in African languages, on several fronts. First of all, there are no known instrumental studies which would support such a claim. Impressionistic reports of voice quality in African languages, such as those qualities mentioned above, almost always describe both [ATR] sets as having a marked voice quality (with perhaps Painter's (1971) description of Anum as a noteworthy exception).

Secondly, from a functional and perceptual perspective, it is not necessarily unreasonable that speakers would try to make the contrast between the two sets as perceptually salient as possible by using a fairly extreme pharyngeal cavity expansion for the [+ATR] vowels and a fairly extreme pharyngeal constriction for the [-ATR] vowels.

While a default along with a more marked setting is most likely the norm for many contrasts, there are cases where speakers prefer the extremes, that is, both marked settings. Consider for example, that in the case of stop series, all languages are expected to have at least minimally the voiceless series (Burquest 2005). Such a claim stems from the fact that voicing and obstruction in the oral cavity present an articulatory conflict. In order to sustain voicing at the glottis, it is necessary to maintain a supraglottal pressure of just 1% above ambient atmospheric pressure, a situation made difficult when there is complete obstruction of the vocal tract. Nonetheless, languages find means of overriding seemingly articulatory difficulties (viz. Keating 1985) and when a second stop series is added to the inventory of a language, it tends to be either the voiced series (such as in Dutch, Spanish, Hungarian, Tamil) or the aspirated series (such as in Cantonese or English.) Lisker and Abramson (1964), who measured VOT for all of the above languages, did find that one of their speakers of American English had a mean voice onset lead of between –88 and –101 ms, in addition to aspirated stops that conformed to the norm of the other speakers. This suggests that using two marked settings and no default setting for multiple stop series (i.e., voiced and aspirated), while not chosen in most languages, is not an inviolable phonetic constraint.

The above example of the English stop series raises a third problem, namely that different speakers of the same language seem, at least based on the fairly small number of multi-speaker studies done so far (e.g. Jacobson 1978), to vary considerably in the way they implement [ATR] contrasts articulatorily. This fact makes it less likely that all speakers of any given language would consistently respect a neutral tongue root position in producing one set of the vowels, assuming such a position could somehow be established. What seems more likely is that languages – even individual speakers of a given language – may differ somewhat as to which gesture is more extreme, the advancing of the tongue root that occurs with [+ATR] vowels, or the retraction of the tongue root that occurs with [-ATR] vowels.

With such theoretical debates running in the background, this dissertation examines how the two types of seven-vowel systems outlined above compare phonetically with nine-vowel systems. Specifically, we will consider how closely the vowels [e] [o] in West and Central African seven-vowel systems generally regarded as

/i e ɛ ɑ ɔ o u/, and the vowels [ɪ] [ʊ] in East African seven-vowel systems generally regarded as /i ɪ ɛ ɑ ɔ ʊ u/, correspond acoustically to the [-ATR] high /ɪ ʊ /and [+ATR] mid /e o/ vowels in nine-vowel languages with cross-height vowel harmony.

Theoretically, the answer to the question of whether it is possible to distinguish between the two seven-vowel systems reported in the literature based solely on phonetic grounds should be "yes" (at least in principle) since [ɪ] and [ʊ] phonetically involve a retracted (or potentially neutral) tongue root, while [e] and [o] are supposedly correlated with an advanced tongue root. Indeed, the fact that both types of systems have been described in the literature would suggest that there is a measurable acoustic and hence perceptual difference.

In reality, the picture is more complex for a number of reasons. To begin with, there are many seven-vowel languages (e.g. Enya) whose vowel system has been represented as /i e ɛ ɑ ɔ o u/ by some linguists (Koloni 1971 as cited in Hyman 1999) but as /i ɪ ɛ ɑ ɔ ʊ u/ by others (Spa 1973 as cited in Hyman 1999). It is quite possible that this discrepancy is due to inconsistent transcription. Hyman considers this closely in his section on the reconstruction of the Proto-Bantu vowel system. He points out that three different vowel systems have been suggested for Proto-Bantu (PB)[3]:

---

[3] My thanks to Larry Hyman for suggesting the use of an IPA character for the "i-cedilla" and "u-cedilla" symbols typically used in Bantuist literature.

a.	i̯	u̯	b.	i	u	c.	i	u
	i	u		ɪ	ʊ		e	o
	e	o		ɛ	ɔ		ɛ	ɔ
	a			ɑ			ɑ	

According to Hyman, system (b) is the phonetic transcription of (a) and thus we are really only concerned with (b) and (c). In system (b), the assumption is that there was an opposition between tense and lax (or [±ATR]) high vowels, such that degree 2 vowels are interpreted as lax ([-ATR]) high vowels. Degree 3 vowels, which have no opposition, are also considered lax ([-ATR]). In (c), the opposition is in the mid vowels, degree 2 being tense ([+ATR]) and degree 3 being lax ([-ATR]).

Hyman therefore raises the question as to which of the two systems should be reconstructed for PB. It would appear that part of the problem in deciding between the two interpretations stems from the inconsistencies in the transcription of present-day synchronic analyses of different Bantu languages. Hyman argues that some linguists use (b) while stating that the phonetic reality is (c). Kuperus (1985), for example, takes such an approach for Londo (A.11), stating that the mid vowels /e o/ *sound* like [+ATR] vowels but *function* as [-ATR]. Others (e.g. Stappers 1973) have used (a) while stating that the vowels are phonetically (c). Still others, such as Maganga and Schadeberg (1992), who use system (b) to symbolize the vowels of Nyamwezi (F.22), have stated that they could find no phonetic evidence to decide whether the difference between [i ɪ] and [u ʊ] was one of [ATR] or vowel height.

According to Hyman, part of the difficulty stems from the (putative) phonetic similarity between degree 2 ([ɪ ʊ]) and degree 1 vowels ([i u]). Thus, some languages analyzed as (c) may in fact be (b). Hyman goes on to state that "[t]he literature thus shows not only possible disagreement, but also confusion over the phonetics and phonology of […] Bantu vowel systems. In fact all three of the systems in (a)-(c) have been used to describe individual Bantu languages" (Hyman 1999:248).

Though Hyman does not take a clear position on whether this transcriptional variation is indicative of genuine indeterminacy, or simply transcriptional inconsistency, he does raise the question of whether it matters which of the vowel systems (a)-(c) represents the proto system. He presents arguments for both of the systems we find synchronically today. Stewart (1970, 1983), for example, argues that the /i e ɛ ɑ ɔ o u/ system developed from an earlier /i ɪ ɛ ɑ ɔ ʊ u/ system, Guthrie (1967) argues for /i e ɛ ɑ ɔ o u/ based first on the frequency that this system occurs and secondly on the proposition that [i ɪ ɛ ɑ ɔ ʊ u] was an intermediary step to the widely occurring 5-vowel system /i e u o a/ (see Hyman 1999 for further detail.) And while Hyman suggests that "the balance is tilted slightly in favor of */i e ɛ ɑ ɔ o u/ (pg. 252), he himself sides with the rarer */i ɪ ɛ ɑ ɔ ʊ u/ (Hyman 2003 and personal correspondence).

Nonetheless, in the absence of contrast between [-ATR] [ɪ ʊ] and [+ATR] [e o] in any given seven-vowel language, it may simply not be possible to tell which set one is dealing with. Hearing the difference between [ɪ] and [e] and/or between [ʊ] and [o] is difficult even in many nine-vowel languages with cross-height vowel harmony (CHVH). This is particularly true in those languages where [ɪ] and/or [ʊ] occupy acoustic vowel space lower than [e] or [o], as has been attested for one speaker of Akan (Hess 1992) or for one speaker of Ikposo (Anderson 1999).

In addition, some linguists have suggested that phonetic contrasts in some (or maybe most or all) seven-vowel languages may not depend on tongue root displacement at all, but rather solely on differences in tongue height, therefore suggesting that for these languages, [ATR] is irrelevant. If this is so, there may be no clear basis for determining whether height two vowels in a seven-vowel system ([i u] being the highest) are either [ɪ ʊ] or [e o]. What would the difference between these two sets of vowels be, if tongue root were not involved? Since there is little to no acoustic data to back up one's decisions in these languages, presumably, one might opt for [ɪ ʊ] for vowels which seem perceptually higher, and [e o] for those which seem somewhat lower. This, however, is a tenuous stance to take in view of what has been previously mentioned about nine-vowel systems: that [e] and [o] have sometimes been measured acoustically as being higher than [ɪ] and [ʊ]. In the absence of any absolute height threshold, there may be no way of telling which vowel is which. Some (such as Clements 1991), who take this line of reasoning seriously, have made alleged indeterminacy one of the main bases for entirely new theories of vowel features.

Clements (1991), for example, presents a uniform phonetic and phonological parameter, characterized in terms of a single, binary feature [open] to account for vowel height. Prior to this 1991 paper, most treatments of vowel height in Bantu described the vowels in terms of the features [high] and [low]. However, Clements points out that analyses have differed as to the nature of the height 2 vowels[4] in a four-vowel height system. Some consider the height 2 vowels [+high], namely /ɪ ʊ/, in a system that also includes /i u/, implying that the height two vowels are [+high] and others [-high][5], or /e o/, in a system that includes /i u/ implying that the height two vowels are mid [-high]. Additionally, since [+high] cannot combine with [+low], [high] and [low] only characterize three heights. Thus many linguists use [ATR] or [tense] to distinguish among vowels with intermediate heights. This, according to Clements, has led to the lack of a uniform model with which to represent vowel height in Bantu.

As a case in point, Clements claims that Kinande is a language with vowel raising. He points out that some linguists have used the feature [ATR] to describe the processes taking place in Kinande, since these features have been described as

[4] Note that Clements numbers heights from the lowest vowel to the highest vowel, such that /a/ would be height 1 and /i u/ would be height 4 in a four-height system. In this dissertation, the more widely accepted way of presenting vowel height is used, namely that /i u/ are height 1 and /a/ is height 4 in a four-height system. In addition, for the sake of consistency in the comparison of four-height systems with five-height systems, I refer to /ɪ ʊ/ has height 2 vowels and /e o/ has height 3 vowels regardless of underlying vowel inventory.
[5] Described above as a difference in the transcription systems for Bantu vowels.

functioning in similar ways in other languages. Clements argues, however, that if we employ [ATR] to distinguish heights 1 and 2 vowels in Kinande at the expense of other closely related Bantu languages, we are claiming that the Kinande vowel system is organized in a fundamentally different way than its closely related neighbors. Specifically, he claims

> There is little or no evidence that this [i.e. that the Kinande vowel system is fundamentally different from its neighbors] is true: the only relevant respect in which Kinande differs from its neighbors is that it has Vowel Raising" (pg. 57).

In addition, Kinande appears to have ten surface vowels, three of which are rule-generated: underlying /i ɪ ɛ a ɔ ʊ u/ gives rise to [i ɪ e ɛ ə a ɔ o ʊ u]. Because Clements can account for this system with the spread of [$open_3$] in a way very analogous to [ATR], he suggests that [ATR] (or [tense]) is completely superfluous in such cases. Gick et al. 2006, however, bring such reasoning into question by providing articulatory evidence that tongue root differences are in fact associated with the height one and height two vowels in Kinande, so that it is not possible to provide a unified phonetic and phonology parameter that would include the phonetic facts of Kinande.

Parkinson (1996), on the other hand, whose Incremental Constriction Model (ICM) does not appeal to supposed indeterminancy, might leave room for cases like Kinande. In ICM the representation of phonological vowel height is based on multiple occurrences of the monovalent feature [closed], all of which are "stacked" directly under each other and linked to the Height node. Parkinson defines [closed] in terms of increased constriction or decreased F1 value: the lowest vowels (highest F1 values) of a language are specified for no occurrences of [closed] while the next to lowest vowels are specified for a single instance of [closed]. Each subsequently higher vowel is specified for an additional occurrence of [closed] so that the highest vowels (lowest F1 values) in a language have the greatest number of [closed] specifications. For example, a 7-vowel system such as /i e ɛ ɑ ɔ o u/ may be specified for up to four heights, but three specifications of [closed]. /ɑ/, being the lowest vowel, is not specified for [closed], /ɛ ɔ/ have one specification of [closed], /e o/ have two specifications of [closed] and /i u/ have three specifications of [closed].

As suggested above, one of the important implications of ICM concerns the feature [ATR]. According to Parkinson, ICM correctly predicts that cross-height harmony is not automatically implicated in all languages with more than three heights, but limited to only those languages in which [ATR] is active, such as Akan where both high and mid vowels cause the same harmony. [ATR] would not be active, though, in cases such as Sesotho, where the raising of a vowel (such as [ɪ] to [i]) is never triggered by a mid vowel [e o], only by high vowels [i u]. Additionally, he claims that languages with four or more heights, but without cross-height harmony, can be described in a manner more consistent with the phonetics of these languages, though it is not clear how this is so. It is also not readily clear where a language like Kinande, whose harmony is not, strictly speaking, cross-height, as in Akan, would fit into the Incremental Constriction Model.

Parkinson makes this important comment:

> Only an examination of a large number of cases of [ATR] assimilation will reveal reliable diagnostics for distinguishing true [ATR] assimilations from height based systems (i.e., languages where the [ɛ]/[e] contrast is based on [ATR] and those where the [ɛ]/[e] are based on [closed]) (99).

This dissertation is a step in this direction by providing evidence from Kinande and LuBwisi, both languages with seven underlying vowels /i ɪ e a o ʊ u/ and three additional surface variants [e o ə], that pattern in a similar fashion acoustically with Ikposo and Foodo, both nine (ten)-vowel languages with [+ATR] harmony.

In addition to the question of whether [ATR] is present or absent in some or all seven-vowel Niger-Congo languages, there remains the question of whether voice quality differences, such as those that have been reported for nine-vowel systems outlined above, can be detected in any of these languages, whether the language has a vowel system with height two vowels transcribed as /ɪ/ and /ʊ/ or /e/ and /o/. Armstrong (1985), for example, has reported some vowel harmony differences related to voice quality for Yoruba (Defoid), which is a language with /e/ and /o/ as height two vowels. But overall, there has been little mention of such voice quality differences occurring in the seven-vowel systems. Others (e.g. Kenstowicz 1994) use the overall lack of report of this phenomenon as an argument that [ATR] is not involved in at least the Bantu seven-vowel systems (which Yoruba is not). This is an important consideration. Casali (2003) suspects that voice quality differences are probably much more widespread than previously reported, citing personal experiences with some West African seven-vowel languages, e.g. Lelemi (Kwa) and Turka (Gur).

Under the premise that an argument from silence is no argument at all, this study proposes that a starting point for determining whether [ATR] is present at all or in some seven-vowel Niger-Congo languages is a comparative acoustic study with nine-vowel languages with cross-height vowel harmony. This study includes two nine-vowel languages from West Africa and nine seven-vowel languages from West Africa and Central Africa all reported to have [ATR] harmony in varying degrees.

Chapter 2 provides a background study of each of the eleven languages and the language families from which they come, along with the rationale for each of their choices. Also included is information on the language consultants, such as demographics and language use. Chapter 3 describes the methodology used in compiling word lists, selecting participants, and in recording and analyzing the acoustic data. Specifically, I detail each of the acoustic measurements and their relevance to this study. Chapter 4 presents the results for each of the acoustic measurements chosen for analysis: F1 and F2 formant analysis, Bandwidth, Normalized A1-A2 (a measure of "spectral flatness") and Center of Gravity. Chapter 5 considers the relevance of the acoustic analysis by relating these results to the question of whether it is possible to know empirically that the degree 2 vowels of seven-vowel languages follow the acoustic behavior of the [-ATR][+high] vowels /ɪ ʊ/, or the acoustic behavior of the [+ATR][-high] /e o/ of the 9-vowel systems with CHVH systems. The results suggest that it is indeed possible to know but that both inter-speaker variation and the function of the vowels within its phonological system must be taken into consideration.

CHAPTER 2

BACKGROUND STUDY

In this chapter, each of the eleven languages featured in this study are presented along with the language families in which they are situated, as well as the rationale for each of their choices. Phonological evidence for each language's vowel system and dominant [ATR] feature are reviewed and, where appropriate, alternative analyses are offered. In addition, pertinent information on each of the language consultants who participated in the study is presented.

The data from the languages featured in this study were chosen from a much larger database that includes 20 datasets representing 14 languages. These datasets include languages with nine- (or ten) vowel systems with cross-height vowel harmony, seven-vowel systems with [-ATR] harmony, seven-vowel systems with [+ATR] harmony, and seven-vowel systems with either restricted harmony (where the mid vowels of roots must agree in [ATR]) and/or coalescent [ATR] dominance (to be discussed in § 2.1). As this study concentrates on the comparison of the acoustic properties of nine- and seven-vowel systems with [ATR] vowel harmony (whether [+ATR] or [-ATR]), 11 languages from two major language families, Kwa and Benue-Congo, were chosen.[6] The three Kwa languages include one Guang and two Left-Bank

[6] The linguistic criteria for the choice of each of these eleven languages are laid out in the subsections which follow. Two practical constraints for these languages (as opposed to many other worthy candidates) include the nine months I spent in Togo during the research period on a Fulbright scholarship

languages. The Benue-Congo languages include two Edekiri and five Bantu languages. Two variants of one of the Bantu languages are also featured for a total of eleven. These eleven are summarized in Table 2.1 and their geographic homes highlighted in red in Figure 2.1.

Table 2.1 lists each of the eleven languages featured in this work, its respective language family, putative underlying vowel system (with allophonic variants, if applicable) and the [ATR] harmony feature that appears to be dominant in the language (indicated throughout this dissertation by the common labels [+ATR] or [-ATR]), according to available phonological evidence. The rest of this section discusses the evidence for these analyses.

Table 2.1: Languages Researched by Family, Vowel System and Dominant [ATR] Feature

Language	Family	Vowel System	Dominant Feature
Dibole	Bantu C	7: /i e ɛ ɑ ɔ o u/	[-ATR]
Ekiti-Yoruba	Edekiri	7: /i e ɛ ɑ ɔ o u/ [ɪ ʊ]	[-ATR]
Foodo	Kwa (Guang)	9: /i ɪ e ɛ ɑ ɔ o ʊ u/	[+ATR]
Ifè	Edekiri	7: /i e ɛ ɑ ɔ o u/	[-ATR]
Ikposo (Uwi)	Kwa (Left Bank)	10: /i ɪ e ɛ ə ɑ ɔ o ʊ u/	[+ATR]
Kinande	Bantu J	7: /i ɪ ɛ ɑ ɔ ʊ u/ [e o ə]	[+ATR]
LuBwisi	Bantu J	7: /i ɪ ɛ ɑ ɔ ʊ u/ [e o ə]	[+ATR]
Mbosi	Bantu C	7: /i e ɛ ɑ ɔ o u/	[-ATR]
Oroko (Londo)	Bantu A	7: /i e ɛ ɑ ɔ o u/[7]	[-ATR]
Oroko (Mbonge)	Bantu A	7: /i e ɛ ɑ ɔ o u/	[-ATR]
Tuwuli	Kwa (Left Bank)	7: /i e ɛ ɑ ɔ o u/	[-ATR][8]

as well as access to language communities via colleagues or affiliates working in West, Central or East Africa.

[7] Note that Kuperus (1985) posits /i ɪ ɛ ɑ ɔ ʊ u/ for the Londo vowel system. See § 2.2.1.1.1 for the rationale of positing /i e ɛ ɑ ɔ o u/ instead.

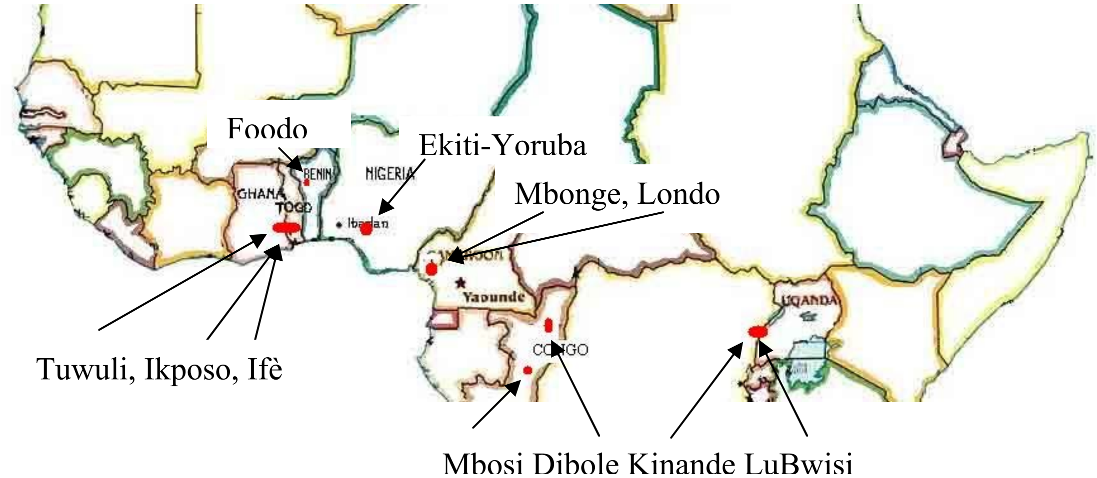

Figure 2.1: Languages Researched in Their (Approximate) Locations

2. 1 Kwa Languages

The Kwa languages are spoken primarily in the southern regions of the West African nations of Côte d'Ivoire, Ghana, Togo and Benin. There are also enclaves in Central Ghana north of the Volta Lake, in Northern Togo and Benin and along the Western Coast of Nigeria where Fon-Gbe reaches. According to Gordon 2005, the region includes 80 Kwa languages with an estimated 20 million speakers (Williamson and Blench 2000). Over half of these languages are within the Potou-Tano branch. Another 30 are the Left Bank languages.

Both five-height and four-height vowel systems are characteristic of Kwa. In Casali 2003, fourteen Potou-Tano languages are reported to have five heights with [+ATR] harmony. In contrast, all of the Gbe languages, which account for 21 of the 30 Left Bank languages, have four-height vowel systems of the /i e ɛ ɑ ɔ o u/ type.

[8] As will be seen in § 2.2.3. Although the most recent analysis of Tuwuli (Harley 2005) argues for [+ATR] as the dominant feature, the evidence for a [-ATR] analysis is perhaps more compelling.

Moreover, if [ATR] vowel harmony is present at all, [-ATR] tends to be the dominant or active feature, surfacing in particular when vowels coalesce. To illustrate coalescent [ATR] dominance, consider the following examples comparing Gichode (Guang), a five-height language with coalescent [+ATR] dominance with Owon Afa (Defoid), a four-height language with coalescent [-ATR] dominance. The Gichode data are from the field notes of Keith Snider and the Owon Afa data from Awobuluyi 1972, both as cited in Casali 2003.

(1) Vowel coalescence in Gichode (phonemic tone omitted)

a. /ɑ + i/ → e
/dɪgɑ idʒo/ → [dɪgedʒo]
'young man's yams'

b. /ɛ+ i/ → e
/ɑtɑnɑtʃgɪsɛ itʃiŋ/ → [ɑtɑnɑtʃgɪsetʃiŋ]
'female twin's veins'

c. /o+ ɪ/ → e
/dʒono ɪlɔ/ → [dʒonelɔ]
'dog's sores'

(2) Vowel coalescence in Owon Afa (phonemic tone omitted)

a. /ɑ + i/ → ɛ
/dɑ iwe/ → [dɛwe]
'buy book'

b. /ɑ + o/ → ɔ
/dɑ opu / → [dɔːpu]
'buy dog'

c. /ɔ + i/ → ɛ
/dɔ iwe/ → [dɛwe]
'burn books'

d. /ɑ + e/ → ɛ
/dɑ ehwe/ → [dɛhwe]
'buy book'

e. /a + u/ → ɔ
/dɑ uju/ → [dɔju]
'buy pounded yam'

In the Gichode data of example (1) the resulting coalescent vowel is always [+ATR]. In contrast, in the Owon Afa data the resulting coalescent vowel is always [-ATR]. As Casali points out, of particular relevance are the forms found in (1a) and (2a) where the sequence /ɑ + i/ is realized as a [+ATR] vowel in Gichode, but as a [-ATR] vowel in Owon Afa. The same sequence of vowels will give differing results depending on the dominant value of [ATR] in the language.

Of the remaining nine Left Bank Kwa languages, five languages – Adele: Kleiner 1989, Animere: Casali 2006, Avatime: Schuh 1995, Ikposo: Anderson 1999, and Tafi: Casali personal correspondence – are reported to have five-height [+ATR] dominance. One language, with the /i e ɛ ɑ ɔ o u/ 7-vowel system, is reported to have [+ATR] dominance (Tuwuli: Harley 2005).

Another Left Bank language, Akebu, is reported to have a ten-vowel system: /i ɪ e ɛ ə ɑ ɔ o ʊ u/ organized within a vowel harmony system based on [ATR] (Storch & Koffi 2000).[9] From what Storch and Koffi describe of Akebu, it is clear that there is vowel harmony of some sort. What is not completely clear is whether the harmony is

[9] According to Storch and Koffi, all ten vowels may also be nasalized.

[ATR] harmony. First of all, Storch and Koffi report that both /ə/ and /ɑ/ are "neutral," occurring after both [+ATR] and [-ATR] high and mid vowels. Moreover, some of the noun classes contain a harmonizing prefix which harmonizes with the vowel in the stem-initial syllable: *ɑ̀-* before [-ATR] /ɛ ɑ ɔ ʊ/ (or before all polysyllabic noun stems), *ə̀-* before /ə/, *ò-* before [+ATR] /u o/ but *è-* before [-ATR] /ɪ/ in addition to [+ATR] /i e/. The presence of a [+ATR] mid-vowel prefix harmonizing with a [-ATR] vowel in the stem is of some interest and merits further study.

In this study, the Potou-Tano family is represented by Foodo, a five-height Guang language. The Left Bank languages are represented by Ikposo (five-height system) and Tuwuli (four-height system).

2.1.1 Foodo

Foodo (ISO 639-3 fod) is a Guang[10] language of the Kwa family spoken by more than 20,000 in the Atacora Department of Northern Benin. According to Plunkett (1991) the principal Foodo villages are all within 10 km of the town of Sèmèrè, the Foodo cultural center, itself comprised of a cluster of eight villages (quarters). Plunkett also reports significant migration of Foodo speakers to other areas of Benin, as well as nearby countries of Togo, Niger, Nigeria, and Ghana. With the possible exception of differences in the use of Rounding Harmony in noun-class prefixes and vocabulary

[10] According to Snider 1990, Foodo is North Guang, along with Gonja, Nkonya, Gichode, Nawuri, Chumburung and Krachi, all spoken in Ghana.

differences among those who have lived in Ghana or have been educated in French, there are no known major variants.

The four speakers (two male and two female) whose data are included in this study are typical of many Foodo speakers, a person who spent part of his or her childhood, adolescence or early adulthood in one or more of these countries, yet considers Sèmèrè as his or her home.[11] All report multilingualism, with Foodo usage in the home and with other Foodo speakers, and Tem (Gur) and Kabiye (Gur) as primary languages of wider communication. Only one of the four speakers was proficient in French, the official language. All claimed to be between the ages of 30 and 45.

The vowel system of Foodo consists of nine vowels /i ɪ e ɛ ɑ ɔ o ʊ u/, which both contrast for length and participate in cross height vowel harmony (CHVH). There is no known description of Foodo vowel harmony apart from the brief account given in Plunkett 1991. Therein we are told that all vowels within the stem must agree in [ATR] value and that prefixes must in turn agree with the stem in terms of [ATR]. With the exception of certain derivational suffixes, which Plunkett assumes are marked for [-ATR] in the lexicon, [ATR] also spreads rightwards from the stem to any suffixes unspecified for [ATR]. While [ATR] harmony in Foodo does tend to spread to possessive pronoun and verb clitics, it is otherwise blocked by word boundaries. Although attested in other Guang languages (viz. Snider 1989), there is no known [+ATR] variant of /ɑ/ in Foodo occurring to the left of [+ATR] vowels.

[11] A fifth speaker (male) participated in the study, but his data were not usable for formant and spectral analyses.

The following are examples of [ATR] agreement in verbal morphology. Stem vowels are bolded while the prefix vowel is italicized and bolded. Only vowels within the phonological word agree in harmony.

(3) a. ***o***-s**óó**lí hɑlɪ
3sC.A.[12]-gather Cl.M.
'he gathered'

b. ***ɔ***-s**ɔ́ɔ́**ˈlí hɑlɪ
3sC.A.-stretch Cl.M.
'he stretched'

2.1.2 Ikposo

Ikposo (ISO 639-3 kpo) is a Left Bank Kwa language[13] (Stewart 1989) spoken primarily in the Plateau Region of Togo, west of the town of Atakpamé and east of Badou. Numbering more than 150,000 speakers in Togo and approximately 7,500 in Ghana, it is the most populous of the group of 14 languages historically known as the Togo Remnant languages (*Togo Restsprachen*)[14]. The genetic affinity of the Togo Remnant languages has been a subject of debate for some time. There is general consensus, though, that the *speakers* of these languages are geographically and culturally related, representing, perhaps, the original inhabitants of their current

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[12] The following grammatical abbreviations are used: C.A. – Completed Aspect, Cl.M. – Clause Marker

[13] Ikposo has been classified along with Tuwuli (Bowiri) and Igo (Ahlo) as either Left Bank or Ka-Togo, (viz. Bennet & Sterk 1977, Williamson & Blench 2000, Gordon 2005).

[14] Harley (2005) attributes this term to Struck (1912).

homelands. It has been proposed that these languages be referred to as the Ghana-Togo Mountain Languages, a geographical rather than genetic designation (Ring 1995).[15]

Six dialects of Ikposo are currently recognized with regional variations within each dialect, most noticeable at the level of tone, but also in lexicon. The six dialects also converge into two major variants that are mutually incomprehensible, one comprising multiple variants spoken in the Litimé area and the Amou-Oblo/Amlamé area, and the other, with less internal variation, comprising the majority of speakers in the Akposo mountains, plain and plateau. There is a 95% or more comprehensibility within the major dialects, but only 79-81% comprehensibility between them.

Although the differences between the two major dialects are numerous (viz. Anderson et al. 1992 and Afola-Amey 1995 for more on Ikposo dialects), what is of most interest to this study is their respective vowel inventories. The Tomégbé variant (representative of the Litimé area) and the closely related Amou-Oblo variant have a 9-vowel CHVH system comprised of /i ɪ e ɛ ɑ ɔ o ʊ u/. In this system, /ɑ/ has no known [+ATR] variant, /e/ being the harmonic counterpart. On the other hand, the other major dialect group (Uwi, Ikponu and Logbo variants) has an additional [+ATR] vowel, /ə/, which occurs only in the root of a word, and which is not the harmonic counterpart of /ɑ/, that is, /ə/ induces [+ATR] harmony but does not itself alternate with /ɑ/ in

[15] The complexities of the classification debate are beyond the scope of this paper. The main issue for their classification, however, centers on their Bantu-like noun-class systems yet high vocabulary resemblances to other Kwa languages. See Harley 2005 and citations therein for further clarification of the issues surrounding the classification of these languages.

harmonizing affixes. As in Tomégbé, /e/ is the harmonic counterpart of /ɑ/ in this dialect group.

The facts of the vowel harmony system of the Uwi dialect of Ikposo, described in Anderson 1999, are summarized here. In addition to showing the distributional restrictions of /ə/ and that /e/, and not /ə/, is the harmonic counterpart of /ɑ/ in Uwi, this paper delimits the extent of vowel harmony in the system. The harmonic processes of Ikposo, exemplified in (4a-i) below, are manifest in both the root and prefixes. Although there are no true suffixes in the language, [+ATR] will spread to the cliticized form of the definite article *yɛ*, as seen in (4a-b). All vowels within the root must agree for [ATR]. The spread of vowel harmony, however, appears to be restricted to the morphological word and root controlled wherein the [ATR] quality of one root does not interfere with the [ATR] quality of an adjacent root (Anderson 1999:202). This is true both in syntactic constructions that have undergone the vowel elision process (4c) and in nominal contexts formed either through the productive Noun-Noun construction (4d) or through compounding (4e). Finally, as seen in (4f-i), within the aspectual sequence of verbal morphology, harmony spreads only to the syllable immediately preceding the verb root. Note that in (4f-g) harmony spreads to the pronoun clitic, a process that is optional in some cases, but it does not spread past the aspectual marker to the left of the verb root.

(4)	a.	ívlɔ́ɔ-ɛ́	[ívlʷɛ̆]
		bird-DEF	
		‘the bird’	
	b.	ívú-é	[ívʷé]
		raffia.sack-DEF	
		‘the raffia sack’	
	c.	Kofí ɑ́-kɑ́ ɔ́-nɑ́ íle	[kofʲɑ́kɔ́níle]
		Koffi 3S-give 3S.POSS-mother ladle	
		‘Koffi gave his mother the ladle’	
	d.	ɔ́lɔ́kʊ̄ + íkó	[ɔ́lɔ́kʊ̄kò]
		salt + gourd	
		‘salt shaker’	
	e.	ɛ́kʊ́-jí	[ɛ́kʊ́jí]
		thing-buy	
		‘merchandise’	
	f.	ɔ́-nɑ̀-lʊ́	[ɔ́nɑ̂lʊ̄]
		3s-NEG-carry	
		‘they did not carry’	
	g.	ó-nè-kù	[ónêkù]
		3s-NEG-drive	
		‘they did not drive’	
	h.	ɔ́-nɑ̀-mɑ́-bɑ́	[ɔ́nɑ̂mɑ̄bɑ́]
		3s-NEG-FUT-come	
		‘he will not come’	
	i.	ɔ́-nɑ̀-mé-mli	[ɔ́nɑ̂mēmlī]
		3s-NEG-FUT-arise	*[ónêmēmlī]
		‘he will not get up’	

The three male and two female Ikposo speakers who participated in this study are all speakers of the mountain/plain dialect. Two participants (one male and one female) grew up in the Uwi dialect area. One male was born in the Ikponu dialect area but lived in the Logbo area. The third male hailed from the Logbo area where the study was conducted and the remaining woman grew up in Amou-Oblo but was fluent in

Logbo. All were multilingual in French and Ewe, and were between the ages of 20 and 43.

2.1.3 Tuwuli

Tuwuli (ISO 639-3: bov), like Ikposo, is one of the 14 Ghana-Togo Mountain Languages classified as Kwa , and is spoken by about 11,000 in the central part of the mountainous area of the Volta Region of South-Eastern Ghana (Harley 2005). The Tuwuli speaking area is bordered on the north and east by Akan and Buem and on the south by Nkonya and Akpafu. There is considerable multilingualism, especially with Ewe and Akan, the major languages of wider communication in this part of Ghana. In addition, competency in English is especially high (59%) in the 15-20 age group among those who have had more than a primary education (Harley 2005).

The five speakers (three male and two female) who participated in this study all claimed to have grown up in Bowiri-Kyiriahi. All are bilingual in Ewe, and four claim at least passive knowledge of Twi (Akan). One of the speakers, male, whose father was Ewe and mother Bowiri, admitted to being more fluent in Ewe than Tuwuli; he left Bowiri-Kyiriahi at age 12 to live in his father's (Ewe) village. All but one had had at least a middle school education and thus more than a passive knowledge of English. The speakers were between the ages of 39 and 61.

Harley 2005 is the first comprehensive study of Tuwuli. Therein it is claimed that Tuwuli, a seven-vowel system consisting of /i e ɛ ɑ ɔ o u/[16], has regressive (anticipatory) [+ATR] and labial harmony between roots and prefixes in both verbs and

[16] Tuwuli also has five nasal vowels /ĩ ɛ̃ ɑ̃ ɔ̃ ũ/ which will not be examined in this study.

nouns, and a limited [-ATR] and nasal harmony between verb roots and suffixes. Harley rightly notes that many West African seven-vowel systems exhibit [ATR] harmony for mid vowels only. Examples of other Kwa languages with mid-vowel harmony include Anufo: Adjekum, Holman & Holman 1993; Attie: Kutsch Lojenga & Hood 1982; and Ewe: Westermann 1930 and Clements 1974, among others. In the Casali 2003 survey of languages with [ATR] dominance, each of these languages has [-ATR] as the dominant feature, surfacing particularly in vowel coalescence. Casali cites only one known case of [+ATR] dominance, that of Legbo, a Cross River language of Nigeria for which compelling evidence exists of coalescent [+ATR] dominance and weak assimilatory [+ATR] dominance.[17] The question remains of whether compelling evidence exists for [+ATR] dominance in Tuwuli. Let us first consider Harley's arguments.

According to Harley, the [ATR] quality of a verb root can be determined from the singular imperative form, a form which lacks any affixation, but that determining the underlying [ATR] value of the prefix is not so straightforward. Examples (5-7) from Harley 2005:60, present his case for anticipatory [+ATR] harmony. As seen in (5a-b) and (6a-b), *o-*/*ɔ-* and *e-*/*ɛ-* alternate in syllables without an onset, while in (5c-d) and (6c-d) *bu-*/*bɔ-*, *bi-*/*bɛ-* alternate in syllables with an onset. In his analysis, Harley assumes a three-way distinction in tongue root position: [+ATR], neutral [-ATR]/[-RTR], and [+RTR], arguing that up to this point, either [+ATR] or [+RTR]

[17] Casali (2003) defines weak assimilatory [+ATR] dominance as involving an affix or affixes in a language which harmonize for [ATR] with root morphemes in some contexts but not in others, and in those contexts in which it does not harmonize, surfaces invariably as [-ATR]. Ikposo, as described above, is an example of a language with weak assimilatory [+ATR] dominance. See Casali 2003 for other types of [ATR] dominance.

could be responsible for these alternations. Harley then reasons that when (7a-b) are considered, the spread of [RTR] to the underlying [+ATR] prefix vowel in (7b) should produce the form *[mɛtɔ]. But since it does not, he concludes underlying [-ATR] vowels for the prefixes of (a) and (b) such that [-ATR] mid vowels raise to [+ATR] high vowels (as opposed to [+ATR] mid vowels) in syllables with onsets.

(5) a. [oku] 'you (sg) died'
b. [eku] 'he/she died'
c. [buku] 'we died'
d. [biku] 'they died'

(6) a. [ɔtɔ] 'you (sg) fell'
b. [ɛtɔ] 'he/she fell'
c. [bɔtɔ] 'we fell'
d. [bɛtɔ] 'they fell'

(7) a. [miku] 'you (pl) died'
b. [mitɔ] 'you (pl) fell'

Harley's analysis, if well-founded, would indeed present a unique case of cross-height vowel harmony in a seven-vowel language with [ATR] mid-vowel pairs. However, there are at least two questions that need to be addressed before concluding necessarily a [+ATR] dominance for Tuwuli. The first of these questions entails the assumption of a three-way distinction in tongue root position. While Harley cites Roberts 1998 as the source of his phonological position, he does not present the arguments in favor of conceptualizing tongue root differences in Tuwuli as a three-way distinction, as opposed to the more accepted binary view of either [+ATR] or [-ATR] dominance. Granted, positing both [+ATR] and [+RTR] helps Harley to account for the fact that /ɑ/ triggers [ATR] harmony in prefixes when it is in a verb root such as *ɔya* 'you (sg) came' or *ɛya* 'he/she came'. Roots with underlying [+ATR] mid vowels will also lower before /ɑ/ in certain suffixes also as well as seen in the example *de* 'rise/go up' → *dɛ-la* 'lift/raise (something)' when the causative suffix *-la* is added (Harley 2005:61).

However, both the behavior of the [i]~[ɛ] and [u]~[ɔ] alternation (which incidentally is widespread in the noun class system) and the spread of [ATR] from /ɑ/ can be explained as [-ATR] dominance if the failure of the 2nd person plural pronoun *mi-* to harmonize with [-ATR] roots is considered exceptional behavior. According to Casali (1997) it is not uncommon for certain affixes in [ATR] harmony languages to exhibit idiosyncratic behavior. Chumburung (Guang), a five-height [+ATR] dominant language, is a case in point. According to Casali 1997, Nawuri (Guang) has an agentive suffix *-pʊ/-pu* which harmonizes for [ATR] with the vowel of the stem to which it is closest: *ɔ-dɔɔ-pʊ* 'farmer' and *o-tiri-pu* 'poor person'. The agentive suffix in Chumburung is cognate with that in Nawuri, but surfaces invariably as [pʊ] (Hansford 1990): *ɔ́-dɔ́ɔ́-pʊ̂* 'farmer' but *ó-tírí-pʊ̂* 'poor man. It fails to harmonize with [+ATR] vowels in the root. One would not posit [-ATR] dominance in Chumburung without more robust evidence.

The example of Chumburung highlights another question Where might other supporting evidence for [+ATR] dominance be found in Tuwuli? For example, given the existence of vowel coalescence in Tuwuli, cases of coalescent [+ATR] dominance, would certainly strengthen the argument of a [+ATR] dominance analysis. As stated earlier, Casali's 2003 survey of [ATR] dominance reveals that [+ATR] dominance in 7-vowel languages with the inventory /i e ɛ ɑ ɔ o u/ is extremely rare. Of the 38 languages with a /i e ɛ ɑ ɔ o u/ vowel inventory listed in his survey, only one, Legbo, has [+ATR] dominance. He supports this analysis with an example of coalescent [+ATR] dominance, wherein /ɔ/ and /e/ coalesce to form a [+ATR] mid vowel: /vɔ e-si/ → [vosi] 'something to do'. In the absence of like supporting evidence for the dominance of [+ATR] in Tuwuli and the fact that [-ATR] can account for the available data, a conservative analysis is preferable.

2.2 Benue-Congo Languages

Covering a vast area of the African continent, the Benue-Congo languages are bordered in the West Africa region by the Gur and Kwa languages, in the Central Africa region by Adamawa-Ubangi languages, and to the north by Afroasiatic. The largest sub-family within Benue-Congo, Bantu, dominates the central and southern parts of the continent. Of the 15 major families that make up Benue-Congo, languages from the Bantoid and Defoid branches are presented here.

2.2.1 Bantu

According to Gordon 2005 there are 681 Bantoid languages spoken in Africa. Of these, the 513 Narrow Bantu languages account for one-third of all Niger-Congo languages. Narrow Bantu stretches across the central portion of the African continent and south to Cape Horn. The Narrow Bantu region is bounded in the North by other Benue-Congo languages, by Adamawa-Ubangi and by Nilo-Saharan. In the South, it surrounds enclaves of Khoisan and Indo-European languages.

Narrow Bantu may be sub-divided in two ways: by the Zones[18] developed by Guthrie (1948, 1967/71)[19] and by its two major branches, Northwest and Central. The Northwest Bantu languages are spoken in Cameroon, Republic of Congo (Congo), Democratic Republic of Congo (DRC), Central African Republic (CAR), Gabon and Equatorial Guinea. Bantu A is found primarily in Cameroon, but also in CAR, Congo and Equatorial Guinea; Bantu B primarily in Gabon, but also in DRC and Equatorial Guinea; and Bantu C primarily in western DRC and Congo but also CAR.

Central Bantu languages are also spoken in the DRC and Congo and the rest of the Central and Southern regions of the African continent from Sudan and Kenya to South Africa.

While Guthrie's system has been widely accepted as a means for roughly classifying Bantu languages, there is equal consensus that this classification does not necessarily accurately reflect the historical or genetic affiliation of these languages

[18] These 'Zones' are currently 17 in number and are represented by letters of the alphabet, A, B, C, etc., plus a two-digit number, which designates a group, such as A.10. Individual languages, members of a group are also designated, such as A.11 for Londo.
[19] See also Hinnebusch 1989 and Maho 2003 for discussions of Guthrie's Zone.

(Leitch 1996, Maho 2003). That said, there are nonetheless morphological and phonological criteria by which Guthrie classified Bantu languages which are pertinent to this study on [ATR] harmony in seven-vowel systems and thus are mentioned here. As it is within the domain of the word where [ATR] harmony, if present, will typically occur, understanding canonical Bantu word formation is important. Foremost is that the Bantu languages featured in this study have verbals which are unambiguously agglutinative.[20] As such, they have invariable roots, often called *radicals* in the Bantu literature, of the form –CVC–. To this radical, various derivational suffixes, often referred to as *extensions*, may be attached to form a *stem*. These extensions are typically a –VC– sequence or single –V–. Minimally, a radical is followed by the verb-final *–a*. If there are extensions, they will occur between the radical and final *–a*. Stems always have a prefix, unless it is a verbal used as an imperative.

Bantu noun roots are typically of the form CV or CVCV. The structure of the Bantu noun is typically *prefix(es)* + *root* where the prefixes are part of a noun class system of grammatical gender (singular and plural.) Also found are types *augment* + *prefix* + *stem* or *secondary prefix* + *prefix* + *stem* may occur, especially in eastern Bantu languages.

As far as phonological criteria is concerned, Hyman (2003) states that most Bantu scholars agree that Proto-Bantu had seven distinct vowels: /i ɪ ɛ ɑ ɔ ʊ u /, with an [ATR] distinction between the height one and two vowels. Many Bantu languages

[20] Not all Bantu languages are agglutinative in nature. See Henson's (to appear) article on Kol (A.831) for an example of a language which is isolating in its verbal system, tense and aspect being marked separately from verbal root words and subject pronoun clitics.

spoken today have merged the first two degrees and consist of five vowels: /i ɛ ɑ ɔ u/, such as Shona (S.11). For those languages with a seven-vowel system, /i e ɛ ɑ ɔ o u/ (e.g., Mbosi-Oléé (C.30)) is very common among the Northwest Bantu languages, with /i ɪ ɛ ɑ ɔ ʊ u/, while rare among 7-vowel languages in general, occurring frequently in East Africa among Central Bantu languages (e.g., LuBwisi (J.20)). There are also five height vowel systems attested in Bantu, albeit rare, as found in Lika (D.20) (Kutsch Lojenga 1999) and Bila (D.30) (Kutsch Lojenga 2003), which has 9 contrastive vowels in the verb system, but only 7 in the noun system. A few languages in zone A, such as Bafia A53, have also added back unrounded vowels.

In an attempt to limit the number of datasets featured in this study, only Bantu languages with the two kinds of four height systems and vowel harmony are presented. Of the six Bantu languages included here, the four Northwest Bantu languages, two Bantu A and two Bantu C, are representative of the common system /i e ɛ ɑ ɔ o u/, while the other two, from Central Bantu, specifically Bantu J, are representative of the less common type, /i ɪ ɛ ɑ ɔ ʊ u/.

2.2.1.1 Bantu A

Of the 53 Bantu A languages listed in Gordon 2005, the vast majority are spoken in south and southwest Cameroon. Only five are spoken totally outside of Cameroon in neighboring Gabon, Equatorial Guinea or Central African Republic. They are bordered by Grassfields, non-Bantu Bantoid, and Ubangian languages to their north, and by Cross River and Ekoid languages to their west along the Cameroon border with Nigeria.

2.2.1.1.1 Oroko

Oroko (ISO 639-3: bdu) is a Bantu A.10 language spoken in the Meme and Ndian Divisions of the South West Province of Cameroon. It is bordered by other Bantu A.10 languages to its immediate east and A.20 languages to its south, by Ejagham (Ekoid) and Kenyang (Bantoid) to the north, and by Korop and Usaghade both Cross River languages, to its west. Gordon 2005 states the population in 2000 as nearly 106,000. Dan Friesen (2002) and Lisa Friesen (2002) estimate the population to be 120,000-140,000 in 2002.

The history of Oroko dialect classification may be found in Johnston 1919, 1921, Guthrie 1953, Dieu and Renard 1983, Kuperus 1958, Friesen and Friesen 2001 and D. Friesen 2002. What is presented here is based on D. Friesen 2002, where it is claimed that the Oroko-speaking people are comprised of ten clans, each speaking a separate but mutually comprehensible dialect. Prior to Friesen and Friesen 2001, classification had been based on Guthrie, recognizing five variants of Oroko called the Lundu Cluster, and still referred to by some as A.11. Kuperus follows Dieu and Renaud's list of eight variants clumped into two major sections, Oroko-west and Oroko-east. This is still reflected in the current version of *The Ethnologue*. D. Friesen (2002) argues that there is evidence (based on Friesen and Friesen 2001) for two major clusters of Oroko: Northwest, consisting of Bima, Lotanga and Longolo with about 95-96% lexical cognates, and Southeast, consisting of Mbonge, Ekombe and Lolue with about

90-92% lexical cognates. These two clusters then share 76-69% cognates with each other while Londo shares 81-83% apparent cognates with the two clusters.

Two of the ten dialects of Oroko were chosen for this study, Mbonge, from the SE cluster and Londo (Balondo ba Nanga). These two dialects were selected primarily for the variation between their vowel harmony systems. Additionally, Mbonge is the dialect that has been selected to be developed as the written form of Oroko. Londo is the subject of Kuperus 1985.

As is sometimes the case for African languages with 7-vowels systems, there is disagreement regarding the status of height-two vowels. According to D. Friesen (2002:19), all the dialects of Oroko have the same 7-vowel inventory: /i e ɛ ɑ ɔ o u/. Specifically, he claims that height two vowels are [-high, +ATR]. In Kuperus 1985, however, the situation for Londo appears to be less straight forward. While Kuperus agrees that there are seven vowels she states that the height two vowels are rather /ɪ/ and /ʊ/ and thus underlyingly [+high, -ATR].

There are three complications associated with the Kuperus analysis. One is the fact that she chooses to transcribe the height two vowels as /e/ and /o/ because "this is the transcription used by Bruens (1948) for Londo, and the most common transcription for the seven-vowel Bantu languages of Cameroon…" (p. 55). Citing Guthrie 1953 and 1967/71, she points out that the height two vowels (which were transcribed with the symbols ẹ and ọ) are considered "half-close," transcribed as [e o] but analyzed as "high, non-ATR", ([-ATR]) which, as Kuperus points out, are normally written [ɪ ʊ]. The second complication is that she states that Bruens (1937:2, 1948:88) posits two intermediate vowels between /i u/ and /e o/, which he transcribes as [ɪ] and [ʊ], stating that the [ɪ] resembles the short "i" of English in words like "bit" but is difficult to distinguish from [e], and that the [ʊ] resembles the short "u" of English "put" but is difficult to distinguish from either [u] or [o]. Kuperus cites five words that Bruens (1937, 1948) used to illustrate these two intermediate vowels: [mokɪ] 'town', [wayɪ] 'wife', [lʊndʊ] 'Londo', [mʊsʊ] 'morning' and [mʊtʊ] 'person'. Kuperus claims, though, that the "i" of the word for 'town' is "realized with a more open variant of the final vowel in non-pre-pausal position" (1985:56). She transcribes this word as *moki* tone ignored here). 'Wife' she transcribes as either *wayi* or *waye* in pre-pausal position but as *wayi* in non-pre-pausal position, 'morning' as *muusu* and 'person' as *moto*. Kuperus rightly concludes that she can find no support for nine underlying vowels in her data. The problem arises from the fact that she transcribes the height two vowels as /e/ and /o/ while claiming that they are in fact /ɪ/ and /ʊ/. How is *waye* ([wayɪ]) different from the Bruens 1937, 1948 transcription? This leads to the third complication arising from Kuperus' analysis.

Kuperus states clearly that the vowels she transcribes as *e* and *o* actually *sound* like [+ATR] mid vowels, rather than [-ATR] high vowels /ɪ/ and /ʊ/. She substantiates her impression by invoking Stewart's 1967 perception of the Akan [-ATR] high vowels as having a "choked" or "strangled" quality associated with them. According to

Kuperus, this quality is missing from the Londo height two vowels.[21] Referring to the Lindau 1978 articulatory study of Akan, Kuperus reminds the reader that height two and height three vowels are often difficult to distinguish perceptually (in languages with both sets). Presumably only an articulatory study could clear up whether the Londo height two vowels are [+ATR] mid vowels or [-ATR] high vowels.

But barring such articulatory evidence and ignoring perceptual evidence to the contrary, Kuperus opts for an interpretation of the height two vowels as [+high], [-ATR] for two reasons. First, she claims to know of only one case where [+ATR] vowels assimilate to [-ATR] vowels, namely Kalaḅarị, which has strong assimilatory, root controlled [ATR]. If the height two vowels are in fact [-high] [+ATR], then for those cases where height two vowels assimilate to height three vowels ([-high] [-ATR] /ɛ/ and /ɔ/), this would be [-ATR] assimilation. The second reason is that invoking [-high] [+ATR] for the height two vowels necessitates an extra feature in her P1 and P2 rules, which is deemed less elegant within the model she adopts, i.e. pre-autosegmental with strictly binary feature specifications. A more economical height analysis, where [+high, -ATR] → [-high] / ____ [-high, -low], is preferred over an [ATR] analysis where [-high, +ATR] → [-ATR] / ____ [-high, -low, -ATR].

But are Kuperus' concerns about the possibility of [-ATR] dominance well founded? Perhaps not, given advances to the theory since Kuperus' pre-autosegmental analysis. For example, Leitch (1996) presents several Bantu C languages with the same

[21] Kuperus discusses the perception of the height 2 vowels only in Londo.

kind of assimilatory processes as Londo. Consider the following comparison of Lokele (C.50) and Londo infinitives and timeless aspect in Londo.

(8)

Lokele Infinitive		Londo Infinitive		Londo Timeless[22]	
a. o-sám-a	‘aimer’	dì-sák-à	‘to dance’	e. ò-sák-í	‘you dance’
b. o-lek-a	‘traverser’	dì-tèk-à	‘to mark’	f. ò-tèk-í	‘you mark’
c. ɔ-lɛmb-ɛ	‘vouloir’	dì-tɛ̀k-ɛ̀	‘to pound’	g. ɔ̀-tɛ̀k-í	‘you pound’
d. ɔ-sɔng-ɔ	‘épouser’	dì-tɔ̀k-ɔ̀	‘to talk’	h. ɔ̀-tɔ̀k-í	‘you talk’

Consider first the infinitives of both languages. In examples (8a) and (8b), the final vowel is *–a.* In examples (8c) and (8d), the final vowel agrees with the radical in terms of roundness and the harmonic feature (which Leitch refers to as privative [RTR], but is being represented here for the sake of consistency as [-ATR]; for more on this topic see § 2.2.1.2). In Leitch's analysis, [-ATR] spreads rightwards from the vowel of the radical to the final vowel *–a*: final vowel *–a* is realized as [ɛ] following /ɛ/ and [ɔ] following /ɔ/. In addition, [-ATR] also spreads leftwards to the prefix class marker *o-* for the infinitive in Lokele (8c) and (8d). Prefix harmony also occurs in Londo, as seen in the timeless aspect (*-i*), shown in (8e-f) with the second person singular pronoun prefix *o-*. Like Lokele, the harmonizing feature spreads leftwards to the prefix in Londo (8g) and (8h).

The main reason for recasting Kuperus's Londo analysis in terms of the spread of the feature [-ATR] (i.e. [-ATR] dominance) is to show that it is possible to retain the perceptual intuitions Kuperus had of the height two vowel qualities and its similarity to

[22] Concerning the “timeless” aspect L. Friesen (2002:14-25) states, “The label ‘timeless’ has been tentatively selected for this suffix, because it is not clear whether it is a tense or aspect, and the suffix gives no indication of when an action has occurred. Instead, it emphasizes the current state of a situation, regardless of when or how the action took place.”

other Northwest Bantu languages in underlying vowel inventory without multiplying features. What remains to be proven is whether the height two vowels bear more acoustic resemblance to the [+ATR] mid vowels or [-ATR] high vowels of nine-vowel languages. This question is revisited in Chapter 5.

In terms of Oroko morphology, Kuperus 1985 and L. Friesen 2004 are in agreement concerning the basic structure of the noun for Londo and Mbonge. Nouns are composed of a root plus a noun class prefix. Typically, the root is disyllabic, but monosyllabic roots also exist. Kuperus also presents trisyllabic roots and while Friesen does not directly address the presence of such roots, her data support that they exist, for example *ba-ŋásálí* 'oranges'.

Verbals, like in many other Bantu languages, consist minimally of a root plus concord prefix and final vowel *–a*. According to Friesen, the prefix may be either an infinitive marker *dì-* or a subject agreement marker, such as *ò-/ɔ̀-* '2s', as were seen in example (8) above. In the case of the imperative, the subject agreement marker is null: *kát-á kósò* 'tie up the parrots!' (L. Friesen 2004:16). The schema presented by Friesen for the complex verbal morphology of Mbonge is as follows:

(9)

Mood +Subject Agreement + Negative + Tense + Aspect 1 + Object Marker + ROOT + Derivation 1 + Aspect 2 + Derivational 2 + Final Vowel (Tense, Aspect, Mood or Focus) + 2p.

As may be seen, any number of prefixes and suffixes may be added to the verb root. This schema is largely the same one presented by Kuperus except that Londo does not have the Object Marker; though she presents data for their existence, Kuperus does not include the two derivational suffixal slots in her schema.

2.2.1.1.1.1 Mbonge

Five speakers of Mbonge participated in this study, three male and two female. One speaker (female) was 51 at the time of the study while the rest were 25-31 years old. All claimed Big Bekondo as their home town. Neither of the women had ever resided outside of their dialect area while all of the young men had lived several years outside of the dialect area mostly for secondary or post-secondary education. All claimed Mbonge as their first language and language spoken in their childhood homes, but were also fluent in Cameroon Pidgin, the language of wider communication for the English-speaking provinces of Cameroon and the de facto language of primary education (D. Friesen 2001). All but one of the women also spoke Standard English, the language of higher education. All the speakers, with the exception of the one woman who did not speak Standard English, had had at least a primary school education. Two of the men had some knowledge of Duala and the other knew school French.

2.2.2.1.1.2 Londo

The five speakers of this study (three male, two female) ranged in age from 51 to 60. All were from the town of Ekondo Titi and claimed Londo as their mother tongue and language of their childhood home. All had lived for some time outside of the language or dialect area but only spoke Cameroon Pidgin, Standard English or some French. All but one of the women had at least a primary school education.

2.2.1.2 Bantu C

The Bantu C languages are spoken in the Congo River basin of the Congo Republic and the Democratic Republic of Congo, an area nearly a thousand miles east to west and north to south (Leitch 1996:2). They are bordered by Adamawa-Ubangian languages to the North, Bantu A to the West, Bantu D to the East and Bantu B and L to the South. According to Gordon 2005, there are 69 languages in nine groups classified as Bantu C. These languages share a number of morphological and phonological properties which distinguish them from their neighboring Bantu languages (Leitch 1996:7).

Leitch 1996, the most comprehensive study of the phonological variation of the vowel harmony system of the Bantu C languages to date, presents data from more than two dozen languages. Included in his study are languages from each grouping of Bantu C guaranteeing a representative study of the entire area, as well as any languages showing important variation in the vowel harmony system, irrespective of the group from which they originate.

Basic to Leitch's analysis of the Bantu C vowel harmony system is the assumption that the Bantu C lexical root morpheme, whether nominal or verbal, has an underlying tongue root specification. Working within a theoretical framework that argues for both [ATR] and [RTR] as privative vocalic features, he claims that the relevant harmonic feature governing the vowel harmony system of all 7-vowel Bantu C languages is privative [RTR] (1996:28). Each underived lexical morpheme is specified for or not for [RTR] ([RTR]/Ø). As it is beyond the scope of this dissertation to evaluate the merits of a privative versus binary feature analysis of Bantu C, and as there is no reason to suspect any a priori articulatory or acoustic difference between the phonological features [-ATR] and [RTR], the labels [+ATR] and [-ATR] are henceforth used to describe Dibole and Mbosi vowels for consistency and comparison across languages.

As for the linguistic facts of Bantu C morphology, according to Leitch, most Bantu C nouns consist of a disyllabic root preceded by a monosyllabic noun-class prefix. Example (10) adapted from Leitch 1996:29 illustrates singular and plural forms of some Dibole (C.10) nominals:

(10)

Noun Class	Form	Morphology	Gloss
1	molómi	[mo[lómi]]	‘husband’
2	bɑɑlómi	[bɑɑ[lómi]]	‘husbands’
3	munsókó	[mu[nsókó]]	‘fetish room’
4	minsókó	[mi[nsókó]]	‘fetish rooms’
5	dikɔ̀ngɔ́	[di[kɔ̀ngɔ́]]	‘spear’
6	mɑkɔ̀ngɔ́	[mɑ[kɔ̀ngɔ́]]	‘spears’
7	eɛ́lɔ̀	[e[ɛ́lɔ̀]]	‘thigh’
8	biɛ́lɔ̀	[bi[ɛ́lɔ̀]]	‘thighs’

Note that in the morphology column the outer brackets delimit the word while the inner brackets delimit the root.

Bantu C verbal forms, like many other Bantu languages, typically have a -CVC– root, though longer and shorter forms are also attested (Leitch 1996:31-32). Typical of agglutinative Bantu languages, the root may be expanded by four extensions, some of which alternate under harmony and others which do not (or may not), depending on the language.[23] These extensions may also then be followed by a pre-final aspectual suffix *-ak-*, finished with the prosodic final vowel (FV), *-i*, *-e*, or *-a*. The root, its extensions, and FV (though Leitch excludes FV *-e* because its variable phonological behavior suggests it is a word-level rather than stem-level suffix) form the verbal stem. The structure of the verbal stem in Bantu C is summarized in (11)

(11) STEM = [[ROOT] + EXT_1 + EXT_2 … + EXT_n + AK + i/a]]

To the stem may be attached an object marker (OM). These two constituents form what is called a MACROSTEM:

(12) MACROSTEM = [OM[STEM]]

This macrostem has any number, including zero, of tense-aspect morphemes, called 'formatives' (FM) preceding it. At the very left edge of the construction is an obligatory subject marker (SM) which agrees in noun class with the subject noun. The verbal WORD, then, includes the stem/macrostem with its formatives and subject marker:

(13) WORD = [SM-FM-FM-[(OM)-STEM]-e]

The following is an example of a verbal morphological word from Dibole (C.10) from Leitch 1995 (as cited in Leitch 1996:35):

[23] Specifically, it is the causative suffix -is- / -y- that does not alternate. It is precisely this suffix which causes [+ATR] harmony in Bantu J languages, LuBwisi and Kinande. An important distinction is that Bantu C languages have root-controlled vowel harmony only. LuBwisi and Kinande also have dominant [+ATR] affixes.

(14)

tò-	ká!-	á-	[bímb	-í
SU1pl-	NEG-	RFLX-	[hit	-COMPL

'We didn't hit ourselves'

The following summary of the basic harmony patterns possible in Bantu C (adapted from Leitch 1996:76-77) should help the reader visualize the kind of variety attested in this family. Note again that Leitch posits privative [RTR] but that [-ATR] is being used in this dissertation for consistency and clarity.

(15) Possible Harmony Patterns in Bantu C

		[-ATR]		
a.	bo-	[hɛk-ɛl]-e	Stem only	Bolia (C.30)
		[-ATR]		
b.	bo-	[hɛk-ɛl]-ɛ	Stem plus final -*e*	Dibole (C.10)
		[-ATR]		
c.	bɔ-	[hɛk-ɛl]-e	Stem plus prefix	Ntomba (C.30)
		[-ATR]		
d.	bɔ-	[hɛk-ɛl]-ɛ	Complete harmony	Elembe-Nkutu (C.60)
		[-ATR]		
e.	bo-	[hɛk-el]-e	No harmony	Unattested
f.	bo-	[hek-el]-e	[-ATR] not underlying	All languages

These examples in (15) represent a generic Bantu C nominal form that includes a noun class prefix, bO-, a verb root -hEk-, an applicative extension -el-, and a word-level FV -*e*. As the table shows, harmony may be confined to the stem as in Bolia (a). Alternatively, it may extend either rightward to target FV -*e* seen in Dibole (b) or leftward to target the prefix, as in Ntomba (c). It may even target the entire word for complete harmony, which it does in Elembe-Nkutu (d). There are no attested cases of a radical having underlying [-ATR] and yet not inducing harmony, as seen in (e), while in (f) all languages have cases where [-ATR] is not underlying.

The choice of Dibole and Mbosi Oléé as representatives of this large class of languages was contingent upon several factors, including availability of speakers of the target languages residing in Brazzaville, where the recordings took place. The primary factor, however, was the desire to represent both leftward and rightward spread of the feature [-ATR]. Dibole was an excellent candidate for lexical rightward spread of the type seen in (15b) and Mbosi Oléé of both lexical rightward spread and post-lexical (single syllable) leftward spread (not seen in example (15)). The latter was deemed especially desirable as it is the only known example of a Bantu C language in which the /a/ induces anticipatory [-ATR] harmony in prefixes. Note that [-ATR] does not spread from /a/ to suffixes in Mbosi. This reportedly rare occurrence of [-ATR] spread from /a/ is one of the important ways in which the Bantu C 7-vowel system differs from the Edekiri (Yoruba and Ifè) languages discussed here. In Edekiri when /a/ occurs in a root, any mid vowel to its left will harmonize for [-ATR].[24] See §2.2.2.1 for further discussion on Edekiri.

2.2.1.2.1 Dibole

Dibole (or "Babole" – ISO 639-3: bvx) is a Bantu C.20 language spoken by about 4,000 people (in 1989 according to Gordon 2005) in the southern half of the Epena District in a sparsely populated part of northeastern Congo. Their nearest neighboring language group, Bomitaba (also C.20) are to their north. Of the three Dibole dialects listed in Gordon 2005 – Southern Dibole (Bouanila), Central Dibole (Kinami), and Northern Dibole (Dzeke) – it is the last of these that was recorded for this study.

The five speakers (three female and two male) who participated in this study ranged in age from 37 to 56. Two of the females and the two males claimed Dzeke as their home town. The third female claimed Brazzaville as her home town but spends her vacations in Dzeke. The two females and two males also claim the Dzeke dialect of Dibole as their mother tongue while the third female grew up with both the Dzeke and Didingo dialects being spoken in her home. All speakers claimed proficiency in French, the official language of the Congo, and in Lingala, one of the two national languages. Three of the speakers also claimed some knowledge of Sango, Kituba and KiKongo. Most of the speakers had a least a secondary school education. The third female had minimally a primary school education.

[24] In some dialects of Yoruba, [-ATR] allophones of high vowel /i/ and /u/ ([ɪ] and [ʊ], respectively) will also in this environment.

2.2.1.2.2 Mbosi Oléé

Mbosi Oléé (ISO 639-3: mdw) is a Bantu C.30 language spoken by approximately 110,000 people in the Cuvette and Plateaux Regions in the central part of the Republic of Congo. The language area is bordered to the north by Koyo (C.30), to the south by Ngungwel (B.70), and to the west by Teke-Tege (B.70). Their nearest neighbor to the east is Likuba (C.30).

Five speakers, three male and two female, participated in this study. They ranged in age from 18 to 38. As with the Dibole speakers, the Mbosi speakers of this study currently reside in Brazzaville but for the most part claim places within the language area as home towns. One of the males claimed Okaya as his home town but had spent the 10 years prior to this study in Brazzaville making trips back to his town from time to time. Another of the male speakers grew up in Endolo, while one of the females claimed Itsegne as her home town. All of the speakers also knew Lingala, with the young man from Endolo claiming it as equal status as Mbosi (his father being a Lingala speaker and his mother a Mbosi speaker). Everyone had at least passive knowledge of French and one of the males a passive knowledge of Teke. Each had a primary school education and at least one year of secondary school.

2.2.1.3 Bantu J

The two Bantu J languages chosen for this study, LuBwisi and Kinande, are classified as part of the Interlacustrine Zone which includes many of the languages originally classified in Guthrie Zones D and E (Bastin 2003). These languages are found in Rwanda, Burundi, Southern Uganda and Eastern DRC where several language families converge: Bantu, Nilo-Saharan and (to a lesser degree) Cushitic. According to Bastin, most Interlacustrine languages have a five vowel system: /i e a o u/. Talinga-Bwisi and Kinande are exceptional in that they both have a seven-vowel system: /i ɪ ɛ ɑ ɔ ʊ u/. Bastin transcribes the system as /i e ɛ a ɔ o u/, but as shall be seen in the individual language descriptions, there is little reason to adopt such a transcription.

Distinctive of both LuBwisi and Kinande is that while seven vowels are phonemic, both languages evidence ten surface vowels, with [e] and [o] occurring as allophones of /ɛ/ and /ɔ/, respectively. There is also a raised allophone of /ɑ/, which will be transcribed as [ə] here. These allophones occur only when there is a high [+ATR] vowel in the word. The exact nature of these occurrences will be considered below separately for each language.

2.2.1.3.1 LuBwisi

LuBwisi (ISO 639-3: tlj) is a Bantu J.20 language spoken in the Bundibugyo District of western Uganda and in the Butalinga County of North Kivu in eastern Democratic Republic of Congo (DRC) where it is known as KiTaalinga. The language is listed as Talinga-Bwisi (ISO 639-3: tlj) in Gordon 2005. According to Gordon 2005, the total population of LuBwisi speakers is more than 84,000. Tabb (2001, 2004), however, estimates the number of speakers to be about 100,000. Neighboring languages include RuKonjo, Runyoro-RuTooro and KwAamba. According to Tabb (1993), LuBwisi and Runyoro-Rutooro share approximately 70% lexical similarity, but Lubwisi and KwAamba only 35%.

Five speakers of LuBwisi, three male and two female between the ages of 20 and 49, participated in this study[25]. Two of the male participants had a post-secondary school education, one male and one female completed 7 years of school, while the second female claimed no formal education. All of the speakers reported either passive knowledge or conversational proficiency in the following languages: English, Kiswahili, Rutoro, Rukonjo, Kwamba. The one female without any formal education did not know English. One of the males also knew Luganda. All five speakers evidenced [+ATR] allophones of [-ATR] mid vowels.

As suggested above, there are two major dialects of Talinga-Bwisi, the variant known as LuBwisi spoken in Uganda and the variant known as KiTaalinga spoken in the DRC. The only known phonology of KiTaalinga is embedded in Paluku's 1998 grammatical description of the language. Cullen (1999) includes a short inventory of LuBwisi segments in her dissertation on LuBwisi narrative discourse, while Tabb 2001/2004, an unpublished document, is the only phonological sketch of LuBwisi to date.

Tucker and Bryan (1957) (as cited in Tabb 2001/2004), Paluku (1998), and Tabb (2001/2004) all agree that LuBwisi and KiTaalinga have seven contrastive vowel phonemes /i ɪ ɛ ɑ ɔ ʊ u/ which, according to Tabb, also contrast for length. At the writing of Cullen 1999, however, there appeared to be an ongoing debate as to whether the [-ATR] high vowels, /ɪ/ and /ʊ/ should be represented in the LuBwisi orthography or

[25] Two of the males and one female claimed to speak "LuBwisi West", and the other male and female to speak "LuBwisi East". According to Waller Tabb (personal correspondence), it is not clear exactly what these terms mean.

not. She claims that it was not clear at the time of the debate whether the [-ATR] high vowels contrasted with the [+ATR] high vowels, as “the differences between the vowels have been determined as either tonal or inferable from context…” (page 54). The debate seems to have been resolved by 2004, however, as Tabb represents [+ATR] high vowels, /i/ and /u/ as a digraph |i̲| and |u̲| and [-ATR] high vowels as monographs |i| and |u|. Tabb (2001/2004:15), in fact, presents clear evidence that these vowels do indeed contrast, as seen in (16)

(16)

i	kù-**tí**ɣɑ̀	‘to leave’	u	kù-**tú**ɑ̀	‘to spit’
ɪ	kʊ̀-**tɪ́**níkɑ̀	‘to overturn soil’	ʊ	kʊ̀-**tʊ́**mɑ̀	‘to send’

The contrastive syllable, in this case root-initial, is bolded. Both tone (high) and context (infinitive) are constant. The [ATR] value of the prefix will be considered later.

If neither tone nor context is at issue, then what is? Cullen, in referring to Rukonjo and Rwamba[26], each of which have seven contrastive vowels, states the issue in the following way: “Lubwisi has all seven *sounds…*” (italics added). Could some other factor have been contributing to the ambiguous status of the height two vowels /ɪ/ and /ʊ/? Tabb (2001/2004) describes as [ATR] harmony the process whereby [-ATR] high vowels become [+ATR] when a conditioning [+ATR] high vowel is present within the word. This process targets three levels: the root, prefixes, and verbal suffixes. In the first case, root vowels /ɪ/ and /ʊ/ become /i/ and /u/ when the [+ATR] causative suffix *–i*

[26] Most likely referring to KwAamba.

is present in verbal constructions. For example, /kʊ̀-kílʊ̀/ 'to be healed' is realized as /kù-kíl-**í**-ʊ̀/ 'to heal' (or more specifically, 'to cause to be healed'). A similar process also happens when the [+ATR] agentive suffix occurs on nouns derived from verbs: /kʊ̀-lìmʊ̀/ 'to dig' becomes /mù-lìm-**ì**/ 'digger' or 'farmer'. Note that Tabb actually presents this as allophonic variation, stating that /ɪ/ and /ʊ/ have allophones [i] and [u]. But as Tabb has already demonstrated that the [+ATR] high vowels contrast with the [-ATR] high vowels, this is clearly a case of neutralization of phonemic contrast, unless, of course, the [i] and [u] of our examples occupy an acoustic space between that of /i/ and /ɪ/, and that of /u/ and /ʊ/, something to which Tabb makes absolutely no allusion.[27]

[-ATR] high vowels of prefixes are also targeted for [ATR] harmony when a [+ATR] high vowel occurs in either the root or the suffix of a word. Examples cited above, where /kʊ̀-kílʊ̀/ 'to be healed' is realized as /kù-kíl-**í**-ʊ̀/ 'to heal', illustrate that the [+ATR] feature of the agentive suffix *–i* targets both the root vowel and the prefix vowel. The word for 'knee' /kù-lú/ [kù-lúʔ] further illustrates the spread of [+ATR] from the root vowel to the prefix.

Both examples of [+ATR] spread, either from a root or suffix vowel are cases of anticipatory or leftward spread of this feature. The third example of [+ATR] spread

[27] Note that I am not contending that Tabb is arguing that this variation is allophonic. He is to a degree limited by the template he uses to write the LuBwisi phonology sketch and the template asks for allophonic variation. Allophonic variation does occur, as we shall see, for the [-ATR] mid vowels, and Tabb rightly underscores this as allophonic variation elsewhere in his sketch while ignoring the alternation of /i/~/ɪ/ and /u/~/ʊ/.

which targets certain suffixes, such as the applicative -*ɪl*, illustrates rightward ATR spread. For example, /kʊ̀-sínd-**ɪ́l-**ɑ̀/ 'to praise for' and /kù-sínd-**íl**-ɑ̀ / 'to groan for'.

In addition to the spread of the [+ATR] feature of high vowels /i/ and /u/ to [-ATR] high vowels /ɪ/ and /ʊ/, [-ATR] mid vowels /ɛ/ and /ɔ/ are also targeted in the speech of some speakers. According to Tabb, [+ATR] variants [e] and [o] occur when /ɛ/ or /ɔ/ is preceded or followed by [+ATR] /i/ or /u/. Anticipatory spread of [+ATR] includes examples such as [ŋ̩kólú] 'scar' and [kì-tèlí] 'type of weed'. An example of regressive spread is [kì-tìßò] 'rope'. Tabb claims at this point that there is inter-speaker variation. Some speakers pronounce this word (and presumably others meeting the same condition) as [kì-tìßɔ̀]. Though he does not explicitly say so in the phonology sketch, it would appear that verbs with [-ATR] mid vowels in their roots would also be subject to [+ATR] spread from the agentive suffix –*i*. Examples such as [ɑ́ɑ́ɣɛ̀ˑ^{n}dɛ́ɛ́jɛ̀] 'he has gone for' and [ɑ́ɑ́ɣèˑ^{n}díè] 'he has gone' where the root /ɛ/ is realized as [e] in the second example before a suffix that includes a [+ATR] high vowel do exist in the description.

Tabb also claims that for those speakers with [+ATR] allophones of /ɛ/ and /ɔ/, a slightly raised variant of the low vowel /ɑ/ also appears in the context of a following /i/

or /u/: compare [mʊ̀-kɑ́lì] 'brave person' versus [mʊ̀-kɑ̹́lì] 'woman'.[28] Note that the low vowel, though subject to raising, is purported to block the spread of [+ATR] onto the prefix.

There also appears to be cases of [-ATR] spread occurring in [-ATR] verb roots where the [+ATR] Perfective suffix [–iɛ] (also known as the modified base suffix according to Cullen 1999) become [-ATR] when following the [-ATR] Applicative suffix -*ɪl*. Consider (17):

(17)

a.	kʊ-hɑˑⁿdɪɪk-ɑ n.cl.-write-FV	'to write'
b.	ɑ-ɑ-hɑˑⁿdiik-iɛ he-PAST-write-MB	'he has written'
c.	kʊ-hɑˑⁿdɪɪk-ɪl-ɑ n.cl.-write-APPL-FV	'he has written for/to'
d.	ɑ-ɑ-ᵐpɑ-hɑˑⁿdɪɪk-ɪ-ɪɛ he-PAST-me-write-APPL-MB	'he has written me'

(17a) shows that the high vowel of the root is [-ATR]. In (17b), the high vowel undergoes [+ATR] spread from the [+ATR] Perfective suffix. Example (17c) contains the [-ATR] Applicative suffix -*ɪl*. And (17d) demonstrates the spread of the [-ATR] value of the Applicative (realized here as just -*ɪ*) to the Perfective suffix.

[28] Note that [mʊ̀-kɑ̹́lì], and other LuBwisi words with a raised allophone of the low vowel, is typically transcribed as [mʊ̀-kə́lì] in this work.

2.2.1.3.2 Kinande

Kinande (ISO 639-3: nnb) is a Bantu J.40 spoken in Nord-Kivu Province in Northeastern Democratic Republic of Congo by more than 900,000 people (1991 estimate). It is bordered to the west primarily by Bhele (D.30); its nearest eastern neighbor is Talinga-Bwisi.

Three males aged 32-36 and one female, age 47, participated in this study. The males are speakers of the Yira dialect while the dialect of the female is unknown. In addition to Kinande, all speak KiSwahili and French. Two of the males had some knowledge of English while the female, who had resided for some time in the USA, was fluent. All had at least some years of high school education. One of the male speakers had also spent two years in seminary in Italy.

The morphology of Kinande is typical of other Bantu languages, namely that a root will have a series of prefixes and suffixes attached to it. Mutaka (1990/1994) introduced the minimal MACROSTEM seen in the Leitch (1996) account of Bantu C, where the optional object prefixes are part of the stem. To this other prefixes are attached, all preceded by the augment. Archangeli and Pulleyblank (2002) summarize the Kinande morphosyntactic structure as follows:

(18)

augment [Word diminutive/ augmentative prefixes [Macro-stem class prefixes [Stem [Root …] …]]]

As in other Bantu languages, various extensions plus the final vowel (FV) may be added to the verbal to extend its meaning. Example (19) (adapted from Mutaka 1995) illustrates the verb 'dance' in the verbal 'we are not dancing for'

(19)	tú-	tɛ́-	βin	-ir	-ɑ̂	[túté βinirɑ̂]
	SM	NEG	dance	APPL	FV	

This study is especially interested in, but not limited to, suffixes which have a high [+ATR] vowel, such as the applicative *–ir* or the causative *–i*, as these are known to induce harmony in the stem and prefixes.

The vowel harmony system of Kinande has been well documented in the literature using a variety of theoretical models (Valinande 1984, Mutaka 1991, 1995, Hyman 1989, Archangeli and Pulleyblank 1994, 2002 among others). The Kinande vowel system parallels that of LuBwisi in that it also has seven contrastive vowels /i ɪ ɛ ɑ ɔ ʊ u/ with an additional three surface vowels [e], [o] and [ə]. These allophones only occur when there is a high [+ATR] vowel in the word. For example, *ɛrɪ-sɛk-ɑ* 'to laugh' becomes *eri-sek-i-a* 'to cause someone to laugh' when the suffix causative *–i* is present.[29] Such alternation has been well attested.

Archangeli and Pulleyblank (2002) point out, however, that the inclusion of the advanced form of /ɑ/ may be controversial since the low vowel has been considered transparent in previous analyses (notably Schlindwein 1987, Cole & Kisseberth 1994

[29] Note that in order to be consistent throughout this paper, I am avoiding the use of subscripted cedilla to indicate high [+ATR] vowels, the system typically used in the literature for Kinande and other languages with a /i ɪ ɛ ɑ ɔ ʊ u/ vowel system.

and Mutaka 1995). Nonetheless, Hyman (1989) and Mutaka (1995) do give an example of a low vowel realized as perceptually advanced (or raised) in the noun for 'woman' *ɔ-mʊ-kal-i* → [ɔ̀múkə̀:lì]. Gick et al. (2006) resolve this issue using ultra-sound imaging. Their results indicate that [+ATR] high vowels and the [+ATR] mid vowel allophones have a tongue-root position which is significantly more anterior than their [-ATR] counterparts. These results were found to hold also for the [+ATR] counterpart of the low vowel in that the low vowel not only transmits the harmonic value of the following [+ATR] high vowel in a word like /mɔ́-tʊ-kɑ-sɑk-írɛ̀/ [mótwəsəkí:re] 'we remained' to the harmonizing prefix, but is itself targeted for [+ATR] harmony in the proper name [kə́gəsu].

2.2.2 Edekiri (Defoid)

The Defoid languages are spoken mainly across the central and southern regions of Nigeria, Benin and Togo. They are bordered by Kwa and Gur on their western border in Togo, by Gur to the north and by Kwa to the south in Benin, and by other Benue-Congo (non-Bantoid) languages in Nigeria. The language family itself consists of the Akokoid dialect cluster, Ayere-Ahan language and Yoruboid languages. Yoruboid is then divided into the Igala dialect cluster and the Edekiri languages, which according to Gordon 2005 are 13 in number. Gordon 2005 groups together eight languages of the Ede language cluster: Ede Cabe, Ede Ica, Idaca, Ifè, Ede Ije, Ede Nago, Kura Ede Nago, and Manigri-Kambole Ede Nago. In addition to these is Isekiri (formally SE Ede), Lucumi (a secret language of Cuba), Mokole (spoken in Benin), Ulukwumi (Nigeria), and Yoruba.

The two Defoid languages considered in this study are from within the Edekiri branch of Yoruboid: Ekiti and Ifè. Ekiti is one of the dialects of the many mutually intelligible dialects of Yoruba which also includes Standard Yoruba which is based primarily on the Ọyọ dialect spoken in Ibadan. Ifè is a member of the Ede language cluster, related to but not mutually intelligible with Standard Yoruba.

2.2.2.1 Ekiti-Yoruba.

Ekiti, one of the Yoruba dialects (ISO 639-3: yor), is classified as an Edekiri (Defoid) language, thus within the Benue-Congo branch of Niger-Congo languages. It is spoken in Ekiti State in Southwestern Nigeria, east of Ọsun State, west of Kogi, south of Kwara and north of Ondo. Ọsun and Ondo States are inhabited primarily by Yoruba speakers, while Kogi and Kwara States have sizeable Yoruba speaking populations.[30]

Five speakers participated in the study of Ekiti, three males and two females between the ages of 29 and 42. All speakers were from the Ekiti State but were currently residing in Ibadan. All were university graduates with high proficiency in Standard English. They were also speakers of Standard Yoruba. Only one claimed to have some knowledge of Nigeria Pidgin. Others had basic proficiency or passive knowledge of Nupe, French, or Hausa. Each had resided in his or her hometown for at least 11 or 12 years before living elsewhere, most having left only upon entrance to university.

[30] Wikipedia estimates the population of Ekiti State as more than 2.7 million. How many of these are Ekiti speakers is unknown.

There are several complications to this data set which must be noted at this point. One of the male's data proved to be unsuitable for formant and spectral analysis and so do not figure into the results. Additionally, according to the speakers who participated in this study there are some 40 major towns in the Ekiti area, each with its own variant. Of the two females, it turns out that one is a speaker of the Mọba dialect. At the time when this research was conducted in 2004, I had been informed that Ekiti-Yoruba had allophonic [-ATR] dominance which targeted not only mid-vowels, but high vowels as well. I was not aware until Przezdziecki 2005 became available that the Mọba dialect, also spoken in Ekiti State, only targets mid vowel prefixes and not high vowels. Of the remaining three speakers, each is from a different local government: Male speaker 1 from Ikere-Ekiti in the Ikere local government, Male speaker 2 from Ilogbo in the Ido/Osi local governments and Female speaker 3 from Ọgọtun-Ekiti in the Ilawe local government. While I realize that I do not know as much as I would like about each of these variants, the three speakers (two male and one female) all claimed to be Ekiti speakers while the fourth speaker (female) claimed to be a Mọba speaker. Differences between speakers that arise in results of the data are discussed in Chapter 4.

All Yoruba dialects, including Ekiti, have an underlying seven-vowel system: /i e ɛ a ɔ o u/. All the dialects exhibit some level of vowel harmony. In SY, for example, vowel harmony is restricted to mono-morphemic nouns. Furthermore, among other things, V_1 mid vowels in nouns with a VCV shape must agree in [ATR] with V_2, so that only words such as those seen in (20) are well-formed.

(20) SY VCV words with only mid vowels (Przezdziecki 2005:76)

ètè	'lip'	*ẹ̀jẹ̀*	'blood'
oko	'farm'	*ọkọ*	'husband'
ekpo	'oil'	*ẹ̀dọ̀*	'liver'
òkè	'mountain'	*ọbẹ̀*	'soup'

Forms such as *eCẹ, eCọ,*ẹCe, *ẹCo, *oCẹ, *oCọ, *ọCe, *ọCo are ungrammatical. Additionally, *eCa and *oCa are also ungrammatical. But *ẹ̀gbà* 'bracelet' or *ọ̀gà* 'chameleon' are considered well-formed.

Other dialects of Yoruba conform to these constraints, but are less restricted in other ways. According to Bamgboṣe 1967, in the Ọyọ and Ẹgbado dialects mid vowel harmony is extended in verb constructions to singular subject pronouns, as seen in (21a-f). As expected, SY does not exhibit this alternation. Examples (21g-k) demonstrate that it is only pronoun vowels with higher mid vowels that are affected by the quality of the vowel in the verb. In later works, such as Archangeli and Pulleyblank 1989, this is accounted for by the spread of the feature [-ATR].

(21) Vowel harmony in Ọyọ, Ẹgbado and SY pronouns (adapted from Bamgboṣe 1967)

Ọyọ & Ẹgbado	SY	
a. mọ lọ	mo lọ	'1s went'
b. mo jó	mo jó	'1s danced'
c. ọ fẹ́	o fẹ́	'2s want'
d. o dé	o dé	'2s arrived'
e. ọ́ wá	ó wá	'3s came'
f. ó kú	ó kú	'3s died'
g. ẹ lọ	ẹ lọ	'2p went'
h. ẹ jó	ẹ jó	'2p danced'

i. ẹ fẹ́ | ẹ fẹ́ | '2p want'
k. ẹ dé | ẹ dé | '2p arrived'

i. ẹ fẹ́	ẹ fẹ́	'2p want'
k. ẹ dé	ẹ dé	'2p arrived'

Przezdiecki (2005) demonstrates a similar process for Mọba 1st and 3rd singular pronouns. In addition, Mọba extends mid-vowel [-ATR] harmony to certain other prefixes such as those using negation and future tense/aspect, illustrated in (22).

(22) Mọba prefix vowel harmony, negation and future (from Przezdiecki 2005)

negatation		future		future neg.	
a. *ọ* ***kẹ̀*** *lọ*	'2s didn't go'	*ọ̀* ***ẹ̀*** *lọ*	'2s will go'	*ọ* ***kẹ̀ẹ̀*** *lọ*	'2s won't go
b. *ọ* ***kè*** *jó*	'2s didn't dance'	*ọ̀* ***è*** *jó*	'2s will dance'	*ọ* ***kèè*** *jó*	'2s won't dance

The bolded prefixes in examples in (22a-b) agree in [ATR] with the verb root. Note that once again, the [-ATR] pronoun prefix, *ọ*, is not affected by the [ATR] of the mid vowel which follows it.

In the dialects of Yoruba we have considered so far, vowel harmony affects only mid vowels. In other dialects of Yoruba, notably Èkìtì, Ìjẹ̀ṣà and Àkúrẹ́, vowel harmony also targets high vowels such that /i/ and /u/ have [-ATR] allophones [ɪ] and [ʊ], respectively. Consider the following examples culled from Bamgbọṣe 1967:

(23) SY and Ekiti mono-morphemic nouns (tone ignored)

SY	Ekiti	
a. *igi*	[igi]	'tree'
b. *ile*	[ule]	'house'
c. *ẹru*	[eɾu]	'load'
d. *ẹbi*	[ebi]	'relations'
e. *iyọ*	[ɪjɔ]	'salt'
f. *iṣẹ*	[ʊsɛ]	'work'

g. *igba* [ʊgba] ‘calabash’

As seen in (23c, d), in SY, [-ATR] mid vowels can precede high vowels /i/ and /u/ and /i/ can occur before [-ATR] mid and low vowels (23e-f). Note that **u-* is not permissible in SY. This is not the case for Ekiti. In (c and d), the [-ATR] *ẹ* of SY is realized as [+ATR] [e] in Ekiti. (23e) illustrates that when a [-ATR] vowel such as [ɔ] occurs in Ekiti, the high vowel /i/ of the first syllable is [-ATR] (or lowered). (23b, f-g) show that *u-* is permissible in Ekiti. When /u/ proceeds a [-ATR] vowel, it is also lowered (or becomes [-ATR]).

2.2.2.2 Ifè

Ifè (ISO 639-3: ife) is also classified as an Edekiri (Defoid) language. It is spoken at the western most end of the Ede language cluster, in the Northeastern part of the Plateau Region in Togo and in the Collines Province of Benin. According to Gordon 2005, the Ifè population of the two countries is considered to be about 182,000. There are three major dialects, Tchetti, spoken around and East of Atakpamé, Dadja (Datcha), spoken South of Atakpamé, and Djama. As a member of the Ede language cluster, Ifè has an 87% to 91% lexical similarity with Ede Nago and a 78% lexical similarity with the Yoruba of Porto-Novo (Benin).

Five speakers of Ifè, three male and two female between the ages of 33 and 50, participated in this research. All five are speakers of the Tchetti dialect and are examples of the multilingualism that exists in the Ifè community. All are conversant in French and Ewe, languages of wider communication, one male knows some Kabiye, another some Yoruba and the third speaks the Houdou dialect of Aja, the language of his father. Two of the speakers also have some command of school English.

Like SY, Ifè has seven oral vowels: /i e ɛ ɑ ɔ o u/[31]. In terms of the aspects of its phonology and morphology pertinent to this study, it patterns more like SY than Ekiti-Yoruba in some areas of its verbal morphology and in its distribution of vowels within the roots of words. Like SY, Ifè has limited vowel harmony. For example, pronoun clitics are not affected by the [ATR] value of the verb root: [32] /ó dʒokó/ 'he sat down' and /ó tʃubúlɛ̀/ 'he fell down' as well as /ó lɔ nɑ́dʒɑ̀/ 'she went to market' and /ó dʒɛ ìkɑ̀tì/ 'he ate porridge'.[33] As for vowel distribution within Ifè word roots, each of the seven oral vowels may occur in monosyllabic words:[34]

(24)

si 'put, set'
se 'collect'
sɛ 'be bitter'
sɑ 'encounter
tɔ̀ 'urinate'
so 'attach'
tu 'pull out'

[31] Ifè also has five nasal vowels /ĩ ɛ̃ ɑ̃ ɔ̃ ũ/ which will not be considered here.
[32] Examples provided by Marquita Klaver.
[33] Note that the potential of [-ATR] spread from the root vowel to pronouns is not an issue in Ifè for unlike SY, all pronouns (except 1ps which is a nasal) or preverbal particles permit only vowels e o or a.
[34] Examples from Gardner and Graveling 2000. Note also that Ifè has three contrastive tones: high V́, low V̀, mid V. Examples with mid tone are not marked with a diacritic.

As for the distribution of initial vowels in nouns, like SY, Proto-Yoruba word-initial /u/ is realized as /i/ in Ifè. For example, the word for house in Proto-Yoruba **ulí* (Akinkugbe 1978 as cited in Przezdziecki 2005) remains *ulí* in Ondo and becomes *ulé* in Mọba and Akurẹ (Fresco 1970 as cited in Przezdziecki 2005) but *ilé* in SY and Ifè. As seen in (25), Ifè permits initial /i/ and /a/ before all vowels, whether [+ATR] or [-ATR]. Przezdziecki claims that aCi and aCu are relatively rare in SY, this is also the case for Ifè.

(25) (Culled from Gardner and Graveling 2000)

ìɖì	'place'	ɑ̀bi	'sin, offence'
igbe	'cry, sound'	ɑyè	'joy'
itʃɛ́	'work'	ɑ̀ɖɛ̀ɛ	'chicken'
ikpɑ́	'power'	ɑ̀bɑ́	'wish'
itɔ́	'saliva'	ɑfɔ̂	'word'
ìbò	'plot'	ɑ̀bo	'lamentation'
ikú	'death'	ɑɽú	'slave

Although word-initial /u/ is not grammatical in Ifè, there appears to be vestigial evidence in complex verb forms that suggests that word-initial /u/ may have existed in an earlier stage of Ifè. For example, as seen in (25) the word for 'cry' in Ifè is *igbe*. According to Klaver (personal correspondence) the verb 'to cry out' is formed by the verb *dɑ́* 'make' + *igbe*. Through the normal Ifè vowel elision processes, the vowel of the verb elides and should result in *[ɖígbe] but in fact produces [ɖúgbe]. When *dúgbe* is nominalized, though, word-initial /i/ resurfaces to give the form [igbe ɖíɖɑ] 'crying'.

Like SY, Ifè also restricts mid vowel collocations within the noun root as seen in (26).[35] Mid vowels must agree in [ATR] value. In addition, when /ɑ/ occurs in second position in the noun, it patterns only with [-ATR] mid vowels /ɛ/ and /ɔ/. *eCa and *oCa are not permitted. Przezdziecki states that ɛCi, ɔCi, ɛCu, ɔCu are also rare in SY. In the Ifè dictionary (Gardner and Graveling 2000), ɛCi, ɛCu, and ɔCu, marked in example (26) with a question mark, are completely absent. The only example of ɔCi is *ɔtí* 'drink'. As this lexical item also exists in SY, it is possible that it is a loan word. These forms appear to be even more restricted than in SY.

(26)

etí	'ear'	?ɛCi	òkpò	'cudgel'	?ɔCi
èɽ̥è	'region'	*ɛCe	oɽ̥e	'good'	*ɔCe
éwo	'head'	*ɛCo	oró	'poison, wickedness'	*ɔCo
èbù	'slice of yam for planting'	?ɛCu	ogu	'war'	?ɔCu
ɛ̀fɛ́	value, precious	*eCɛ	ɔbɛ̀	sauce	*oCɛ
ɛ̀fɑ̀	female excision	*eCa	ɔlɑ̀	life	*oCa
ɛbɔ	sacrifice	*eCɔ	ɔ̀bɔ̀	dirt, filth	*oCɔ

In addition to mid-vowel collocation restrictions, Ifè also demonstrates coalescent [-ATR] harmony as may be seen in example (27), culled from Kohler 1984/2000. Note that while this is not the complete picture of vowel hiatus and

[35] Exceptions do exist as in Yoruba, such as from loan words or compounding. These will not be considered here.

coalescence in Ifè, (for example, Kohler presents no examples of $V_{[-ATR]}$ + [i][36]) what is clear is that whenever a [-ATR] vowel is followed by a [+ATR] mid vowel, the resultant coalescence is also [-ATR].

(27) Vowel coalescence in Ifè (phonemic tone omitted)

a. /ɑ + e/ → ɛ
/o kpɑ edʒo/ → [okpɛdʒo]
'he hit a snake'

b. /ɔ + e/ → ɛ
/o kɔ egi/ → [okɛgi]
'she carried wood'

c. /ɛ + o/ → ɔ
/o nɛ ogugu lakũ/ → [onɔgugulakũ]
'it has large roots'

[36] Based on the example of *dúgbe* 'to cry out' from [ɖɑ́ + igbe], where /ɑ/ elides, we can infer that most likely /ɑ + i/, in those cases where word-initial /i/ comes from protoform **i*- and not **u*-, /ɑ/ would also elide rather than coalesce.

CHAPTER 3

METHODOLOGY

As presented in Chapter 2, the languages chosen for analysis in this study - Ikposo and Tuwuli (Kwa, Left Bank), Foodo (Kwa, Guang), Londo and Mbonge (Oroko, Bantu A10), Dibole and Mbosi (Bantu C), Kinande and LuBwisi (Bantu J) and Ekiti-Yoruba and Ifè (Defoid, Edekiri) are representative of many seven- and nine-vowel systems with [+ATR] or [-ATR] harmony. The data for this study are drawn from a large database which was collected on the African continent between November 2003 and November 2004.[37] Participants included native speakers from a total of 20 languages spoken in Ghana, Togo, Benin, Nigeria, Cameroon, Congo Republic, Democratic Republic of Congo and Uganda.

Presented in this chapter are the methodology for word list compilation (§3.1); data collection collection procedures, including choice of consultants and recording procedures (§3.2); , and the acoustic measures undertaken (§3.3).

3.1 Word lists

The words used for the analysis of the vowel system of each language in this study have been culled from larger word lists prepared beforehand by consulting a variety of sources: published articles, published dictionaries, private lexicons or databases, unpublished manuscripts and, in most cases, in consultation with fellow

[37] This study was funded in part by a Fulbright Grant and by the generous donations of friends and family.

linguists *sur place*.[38] In those cases where a field linguist did not accompany me to the recording sessions, each wordlist was also checked with a language consultant and adjustments made prior to recording.

From the larger word lists, smaller word lists, with two words for each vowel, were chosen for the purposes of analysis. Ten repetitions were recorded for each word making for a total of 20 tokens of each vowel. These word lists may be found in the Appendix. The Londo word list is shown here for illustrative purposes.

(28) Londo Bantu A.10 (compiled from Kuperus 1985)

i	[dì-**sìs**à]	‘to frighten
	[dì-**tít**à]	‘to be small’
e	[dì-**sèk**à]	‘to shape (carve)’
	[dì-**tèk**à]	‘to mark’
ɛ	[dì-**sɛ̀b**ɛ̀]	‘to cradle’
	[dì-**tɛ̀k**ɛ̀]	‘to pound’
ɑ	[dì-**sɑ́k**ɑ̀]	‘to dance’
	[dì-**sɑ̀k**ɑ̀]	‘to want’
ɔ	[dì-**sɔ́s**ɔ̀]	‘to suck’
	[dì-**tɔ̀k**ɔ̀]	‘to talk’
o	[dì-**kóf**ɑ̀]	‘to hold’
	[dì-**sòs**wɑ̀]	‘to wash’
u	[dì-**túk**ɑ̀]	‘to suffer’
	[dì-**tút**ɑ̀]	‘to peg out skin, make drum’

Londo is representative of the majority of the word lists found in the Appendix. The bolded characters highlight the radical where the target vowels are located for this

[38] I owe a considerable debt of thanks to numerous SIL and other linguistic colleagues who assisted me in the compilation and checking of all but one of the languages featured in this study.

Bantu language. With the exception of one of the words for /o/, *dìkófà* 'to hold', the onset of the target vowel is an alveolar consonant. An attempt was also made to include words that differed by tone.

For the most part, the words in this study were recorded in isolation, i.e. without carrier phrases. Ladefoged (2003) suggests that, in general, it is a good idea to record words in a carrier phrase in order to avoid list intonation and to be able to more accurately measure the lengths of segments which contrast. However, my decision to not use carrier phrases for the Kwa (Left Bank) and Edekiri languages was based largely on prior experience in Ikposo. In previous research on Ikposo, a tonal language like all the other languages featured in this study, I had noted that list affects are generally not noticeable in multiple repetitions of the same word, especially for non-low tone tokens. In addition, vowel hiatus (elision and gliding) are widespread in these languages whose nouns are primarily of the shape V-CV (the exception being Tuwuli whose nouns are primarily CV-CV) and I wished to ensure that the initial vowel remained intact. The disadvantage of not using a carrier phrase is that Yoruba has phrase final vowel lengthening, something I became aware of only after this research was completed (Prezezdzieki 2005). Determining the boundaries of the target vowels in the Edekiri languages is therefore more difficult but not impossible. This phenomenon is also quite noticeable in certain Ifè speakers and is taken into account in the analysis.

This study focuses primarily on vowels in root position. Decisions on the classes of words chosen for recording were based on three main criteria: word formation, the domain of [ATR] harmony and the presence of allophonic variation. Some decisions concerning word choices, including part of speech, were motivated by research concerns beyond the scope of this study and do not affect its outcome.

Nouns of the syllable type V-CV were chosen to record for Ikposo and Ekiti-Yoruba. This would ensure the possibility of researching both the “root” vowel and its harmonizing “prefix.” Of the four languages in this group, Tuwuli alone has an active prefixing noun class system. Words typically have the syllable structure CV-CV, though a few V- noun classes give rise to a V-CV syllable structure, notably class 4a words, which take *ɔ-/o-*. Ikposo, Ifè and Ekiti all greatly favor VCV syllable structure. However, Ifè and Ekiti lack noun class systems and thus the initial V can hardly be called a prefix, but should more properly be considered a part of the root. Ikposo, on the other hand, has vestigial evidence of a former noun class system (Anderson 1999). In Ikposo and Ekiti, the initial vowel harmonizes in [ATR] with the following vowel of the root; this produces [-ATR] allophonic variation of high vowels in the case of Ekiti. In Ikposo, where all vowels except /ə/ are permitted word-initially, nouns allow the greatest flexibility for measuring the extent of vowel harmony from the “root” syllable. Nouns were chosen for Tuwuli for similar reasons as Ikposo. On the other hand, vowel harmony in Ifè is limited to mid-vowels. Therefore some nouns that illustrate mid-vowel harmony, as well nouns with a [+ATR] high vowel in the first syllable, but [-ATR] vowel in the second syllable, were chosen in addition to verbs in their infinitive (elicitation) form.

Verbs were chosen for the Foodo wordlist. Doing so necessitated a carrier phrase that would illustrate [ATR] harmony in the harmonizing pronoun clitics. The carrier phrase that was chosen is *ɔ-/o- _____ halɪ*, roughly translated as "he/she _____ed." In addition, care was taken to elicit words with long vowels in order to avoid the centralization inherent to the short vowels of Guang languages (Casali 1997).[39] Both monosyllabic and di-syllabic words were included; in the case of the di-syllabic words, the target vowel is always in root initial position.

The rest of the languages, all Bantu, present a very different scenario. As seen in §2.2.1, many Bantu languages are agglutinative: a verb consists of an invariable core (or radical) of the form –CVC– to which various prefixes and suffixes are attached. As the target vowel for the bulk of the analysis is word medially, Bantu verbals present a natural segmental frame for recording. For all six Bantu languages in this study, all vowels may occur in radical position. In addition, in the two Bantu J languages, the [+ATR] allophones [e] and [o] of [-ATR] mid-vowels /ɛ/ and /ɔ/ also occur in the radical when a conditioning [+ATR] high vowel is present. Since all the vowels, including their allophonic variations may occur in the radical, either nouns or verbs would serve the purposes of this study.

There is more than one way to compile a wordlist for formant and spectral analyses. One way is to collect and analyze a large list with several hundred words but few repetitions and thus determine the character of the vowels in the various environments in which they occur. Another is to limit the list, and draw from the list one or more words for each vowel. When limiting the list, more care needs to be taken

[39] Note that eliciting words with long vowels also helps to avoid inherent undershoot which involves not quite reaching the target, a phenomenon especially noticeable in rapid speech (Lindblom & Moon 1988).

to control for certain variables, such as tone and consonant onset (and potentially coda), as well as recording more tokens for statistical purposes.

I opted for variations of the latter strategy for several reasons. First, multiple repetitions of vowels in the same environment ensure that potential outliers do not overly weight the results. Second, formant transitions are most noticeable at consonant onsets. Limiting the onset consonant to one place of articulation (in this case, alveolar or other coronals) allows for a constant in cross-linguistic comparison. Third, limiting the wordlists is more pragmatic: because I would be collecting data from 20 languages in divergent locations on the African country within a 14-month period, I would not have the time to do a pilot study for each language to determine the best data elicitation strategy for each. As it were, the first three languages that I recorded, Ifè, Ikposo, and Foodo, served as test languages for future wordlist decisions. While recording Ifè data, I noted that the mid-toned target vowels were the most robust in amplitude for all vowels. Based on those results, the list I developed for Ikposo was based almost exclusively on nouns with mid-tone in the second syllable. This decision proved to be less ideal for Ikposo: high tone would have given better results, especially for high vowels which have inherently low amplitudes. I settled upon a combination of high tone and low tone words for languages with two tones, and high and mid tone words for languages with three tones, supplementing with low tone only when absolutely necessary.

Ideally, in selecting the consonant preceding the target vowel, initial glottals, which least affect the formant structure of a following vowel, should be chosen. While this was in fact possible for eight of the 20 words used for the Kinande analysis, glottals are not as plentiful in the rest of the languages as alveolar consonants are. Hence wherever possible, words with voiceless alveolar obstruents in the onset of the syllable containing the target vowel were chosen for recording. However, coronal consonants are not without problems. Stevens and House's (1963) study of English demonstrates that the steady state F1 values of vowels after coronal vowels /θ ð s z ʧ ʤ/ do not differ greatly from the F1 values in "null" isolated vowels or vowels following /h/. F2 values for the steady state of vowels, however, exhibit considerable shift from null values. Coronals, in particular, cause centralization that is reflected in a shrinking of the F1/F2 vowel space. This is particularly noticeable in the high back vowel /u/. See Chapter 4 for any issues in the formant analysis arising from the choice of alveolar consonants.

3.2 Data Collection Procedures

3.2.1 Speakers / Participants

Ladefoged (2003) suggests that under ideal circumstances, six to ten speakers of each sex should participate in one's study. Citing the example of Pirahã where women replace the /s/ of male speech with /h/ in their own, he notes that there may be systematic differences between male and female speech. Such an approach contrasts with the precarious one he and others previously used, namely to describe the phonetics of a language based on the speech of one speaker. Doing so can easily result in analyzing the data of that one speaker who is not representative of his or her speech community, or who perhaps represents one strategy among several competing strategies. Considering the wide cross-linguistic scope of this current study, it was necessary to limit the number of speakers to five. Females were included in the study because their speech patterns tend to be underrepresented in the literature. However, because men living in rural settings tend to be less occupied than women with the labor intensive needs of family, it tends to be easier to procure the help of male language consultants than female. Therefore, the data sets were obtained from samples of populations that include three males and two females.

For each data set, effort was made to procure the assistance of speakers who were known to be competent speakers of their language between the ages of 25 and 60 and who had no noticeable speech or hearing impediment. Moreover, in order to control the interference of fundamental frequency (F0) with the F1 values of high vowels, wherever possible an effort was made to identify speakers with medium pitched voices.

Further details concerning the participants of each language community included in this study may be found in Chapter 2.

3.2.2 Recordings

Each word of the larger word lists was recorded directly onto the hard drive of a Sony Vaio PCG-GR250P laptop computer with the aid of either a Shure SM58 dynamic microphone or a Labtec AM-222 condenser microphone and the Cool Edit 2000© program set at a 22Kh sampling rate. When the dynamic microphone was used, an iMic external sound card was also used in the recording process in order to minimize the recording of internal machine noise. The participants were instructed to hold the microphone just in front of their chin, and not resting upon it, with the head of the microphone just below the lower lip to avoid puffs of air directly into the microphone.

As a rule, the dynamic microphone was used during the recording sessions and the condenser used whenever the dynamic microphone set-up began to malfunction. As anyone who has spent any amount of time in the tropics attempting digital recordings knows, heat, humidity, dust, bumpy roads and baggage handlers are not the friends of electronic equipment. The set-up with the dynamic microphone worked without incident during the first two months of recording sessions. Then the i-Mic and the input jack of the Shure microphone had to be replaced. During the trip to Uganda the dynamic microphone set-up functioned intermittently and thus the condenser microphone was used for part of the LuBwisi and Kinande recording sessions. The condenser microphone only functioned when plugged into the computer's internal sound card. This unfortunately leads to an approximately -36 to -42 dB offset from zero that could not be corrected for during recording.

3.2.3 Procedure

Though procedure varied somewhat from language to language, typically, a speaker was presented the larger word list and the words were reviewed together, often with the assistance of either a linguistics colleague or a language consultant who had been prepped to act as intermediary between me and non-speakers of French or English. The speaker was instructed that each word was to be repeated ten times. In order to not overly fatigue either the language consultant or myself in keeping track of the number of repetitions, the repetitions were broken into three manageable sets, with the words repeated three times, three times and then four times. Between each set of three or four, I checked for either insufficient amplitude or clipping and recorded extra repetitions as necessary.

3.3 Acoustic measures

As discussed in Chapter 1, researchers have examined a number of acoustic measurements in order to determine which one(s) best distinguish [+ATR] and [-ATR] harmony pairs. Using PRAAT 4.3 acoustic software the following measurements of each target vowel within its segmental frame were taken and recorded in an Excel spreadsheet and those used later for statistical analysis, imported into the SPSS 14 statistical software tool:

(29) Acoustic Measurements

1. Vowel Duration
2. Fundamental Frequency (F0) and Measures of the Spectral Slope
3. First three formants (F1, F2, F3)
4. F1 Bandwidth (B1)
5. Spectral Flatness (Amplitude of the strongest harmonic of F1 and amplitude of the strongest harmonic of F2)
6. Center of Gravity

3.3.1 Duration

Token and vowel length are potentially useful information to the researcher of [ATR] for it has been noted for some languages with voice qualities differences (such as Bai: Edmondson and Li 1994) that breathy voice syllables have shorter durations than other voice qualities. This is not to suggest that the voice quality differences that have been reported to exist for some African languages with [ATR] vowel harmony emanates from the vocal folds as it does for Bai, but rather to vocal register differences. However, researchers such as Berry (1957) have mentioned such differences for Akan. And thus, other researchers have occasionally included vowel duration in their acoustic studies of [ATR], although not always because they were convinced that source rather than filter voice quality differences existed between the vowel sets.

The Hess 1992 study of Akan, for example, is the first acoustic study of an [ATR] vowel harmony system to test for vowel duration differences between harmony sets. Hess suggests the possibility that length may play a factor in distinguishing [ATR] pairs, pointing out that vowel duration plays an important part in distinguishing tense/lax vowel pairs in English with lax vowels having shorter durations than tense vowels. Since Akan does not have any perceptually salient (source) voice quality differences, such as breathy voice, [-ATR] vowels could potentially be shorter than their [+ATR] counterparts. And while she does find such a tendency, their differences are not statistically significant.

The Guion et al. 2004 study on Maa also examined duration differences. These were not found to be significant for [ATR] harmony pairs, nor for [-ATR] /ɪ/ and [+ATR] /e/, which overlap in acoustic space for some speakers. On the other hand, duration differences for [-ATR] /ʊ/ and [+ATR] /o/, which also overlap for some speakers of their study, did prove to be significant: [-ATR] /ʊ/ was significantly shorter than [+ATR] /o/. Assuming that the Edmondson and Li 1994 finding for Bai breathy vowels is normative, one would expect the opposite results, namely that [+ATR] /o/ would have significantly shorter durations than [-ATR] /ʊ/. Understanding the importance of these results is further complicated by the electroglottographic data from one of the Maa participants which showed slightly less constriction at the glottis for [+ATR] vowels than for their [-ATR] counterparts. The authors admit that voice quality differences, though previously reported for Maa, are not readily perceptible in the data they have.

Finally, Przezdziecki (2005) also conducted duration studies on the data of the three variants of Yoruba in his study. He finds for an Akurẹ speaker that [+ATR] front vowels are significantly shorter in duration than their [-ATR] counterparts. This is not the case, though, for back vowels. Mọba and SY [+ATR] mid vowels are slightly shorter than their [-ATR] counterparts, but their differences are not statistically significant. Such findings may be indicative of a tendency for slightly laxer phonation of [+ATR] vowels, but without an EGG follow up study, this is difficult to substantiate.

In sum, the results across the languages for which duration has been measured are mixed. Differences tend not to be significant and no particular pattern emerges. As no particular pattern linked to [ATR] emerged from the duration measurements in this study, the results are not reported. However, duration measurements are reported where they help to clarify instances of inherent undershoot (see Sections 4.2.9 and 4.2.10.)

3.3.2 Fundamental Frequency and Measures of the Spectral Slope

Fundamental Frequency (F0) measurements have figured in certain [ATR] acoustic studies that include measures of spectral slope. Such studies are based in a hypothesis set forth by Halle & Stevens (1969) that [ATR] harmony pairs might be distinguished by mode of vocal fold vibration. The expectation is that [+ATR] vowels would have less vocal fold contact that in turn would result in decreased amplitude of the second or higher harmonics in relation to the fundamental than [-ATR] vowels.

Both the Hess 1992 study of Akan and the Przezdziecki 2005 study of Yoruba include measures of the relative amplitudes of H2 (the second harmonic of the fundamental) and H1 (the first harmonic of the fundamental or F0). Przezdziecki also examined the relative amplitudes of the harmonic associated with F1 and the H1. Hess could find no pattern for the vowels of the Akan speaker in her study. Przezdziecki, on the other hand, did find significant differences between vowel harmony pairs for one Akurẹ and one SY speaker: as predicted by the Halle & Stevens 1969 model, [+ATR] vowels had higher values than their [-ATR] counterparts. As it turns out, these differences, although statistically significant, are not important. There is a strong possibility that the differences may be attributed to the influence of F1 frequency either on the amplitude of F1 or on the amplitude of the second harmonic. In fact, as Przezdziecki points out, it has been argued that only vowels with similar formant values can be reliably tested for voice quality (i.e. vocal register) differences indirectly. When vowels with differing F1 frequency values are compared, H2 and F1 amplitudes will most likely be boosted for one of the vowels over the other, resulting in instrumental skewing that could falsely indicate a breathiness or creakiness not auditorially perceived.

Because of the general unreliability of spectral tilt studies for vowels with differing formant values, no such measures were taken in this current study. Another type of harmonic differential study was undertaken which involves a normalization of the relative amplitudes of F1 and F2 (A1-A2). This will be described in §3.3.5 on spectral flatness.

It should be noted that the fundamental frequency (F0) was also measured for internal controls but is not reported here. The measure itself, as seen Figure 3.1, was taken at the same point in the steady state of the vowel as the bandwidth of F1 (B1) and the measurements needed for the spectral flatness study.

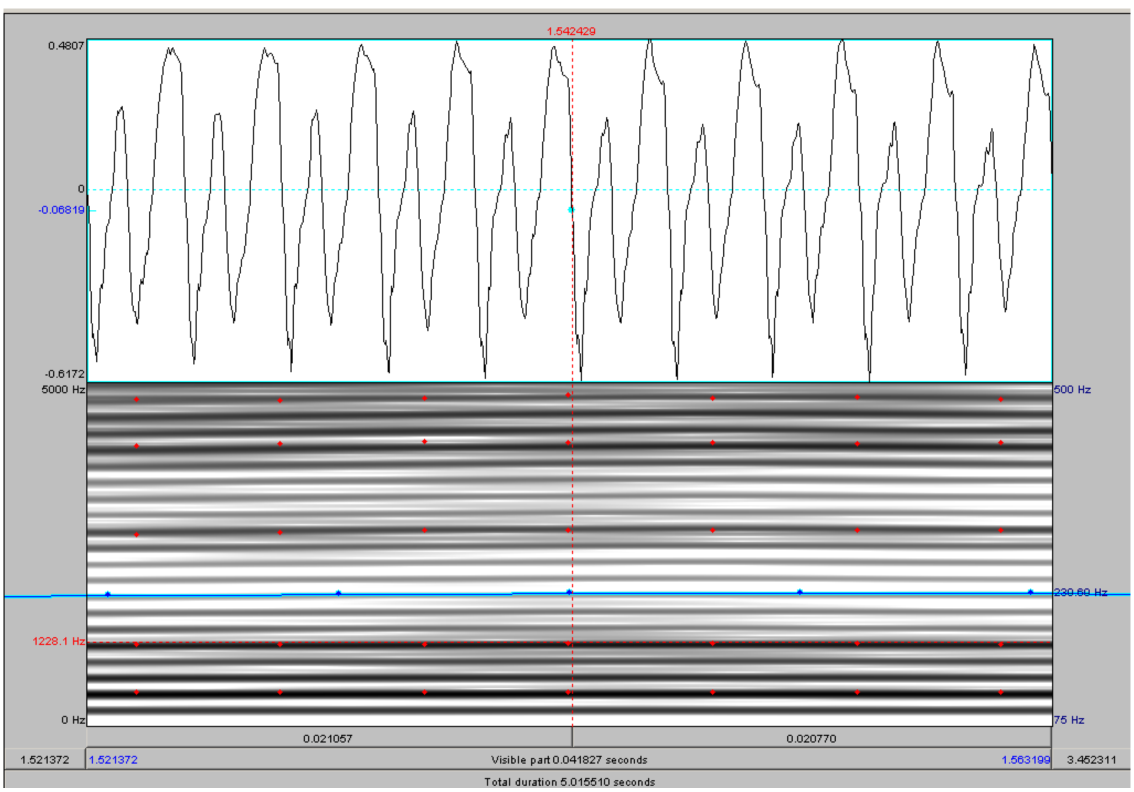


Figure 3.1: F0, B1, and F1-F3 for A1-A2 measurements
(vowel [o] in Ifè *so* ‘to attach’, speaker 4F)

3.3.3 Formant measurements

There is more than one method to sample vowel formants. One way is to take a single slice of the waveform in the center of the vowel. This method is satisfactory particularly in those cases where vowel formants are fairly stable. As will be seen, this is the technique that was used for the observed formant values for the spectral flatness measurements. Another technique, however, takes an average of several glottal pulses within the steady state of the vowel in order to factor in a certain amount of movement within the steady state. This latter technique was applied for the formant analysis; between five and ten glottal pulses have been included in each formant measurement, depending on the length of the target vowel. Measurements were taken within the steady state near the center of the vowel with effort made to stay clear of such transitional effects as those found after obstruent release or transition to a following obstruent or sonorant.

Figure 3.2 displays the waveform and wideband spectrogram for a token of the Ifè word *so* ‘to attach’ as uttered by Speaker 4F. The area shaded in pink is the steady state of the vowel [o] of this token from which F1, F2 and F3 were calculated. The red dotted lines trace the first five formants for this vowel. The blue line is the pitch tracker. Figure 3.3 displays the same area of the waveform but coupled with the narrowband spectrogram display. Some of the early formant analysis was conducted with the aid of the wideband spectrogram. But since there is no difference between the formant tracks of the two spectrogram displays, much of the analysis was conducted with reference to the narrowband spectrogram. Figure 3.4 displays the pulses selected (in this case, 10) for F1, F2 and F3 formant analysis from the middle of the steady state.

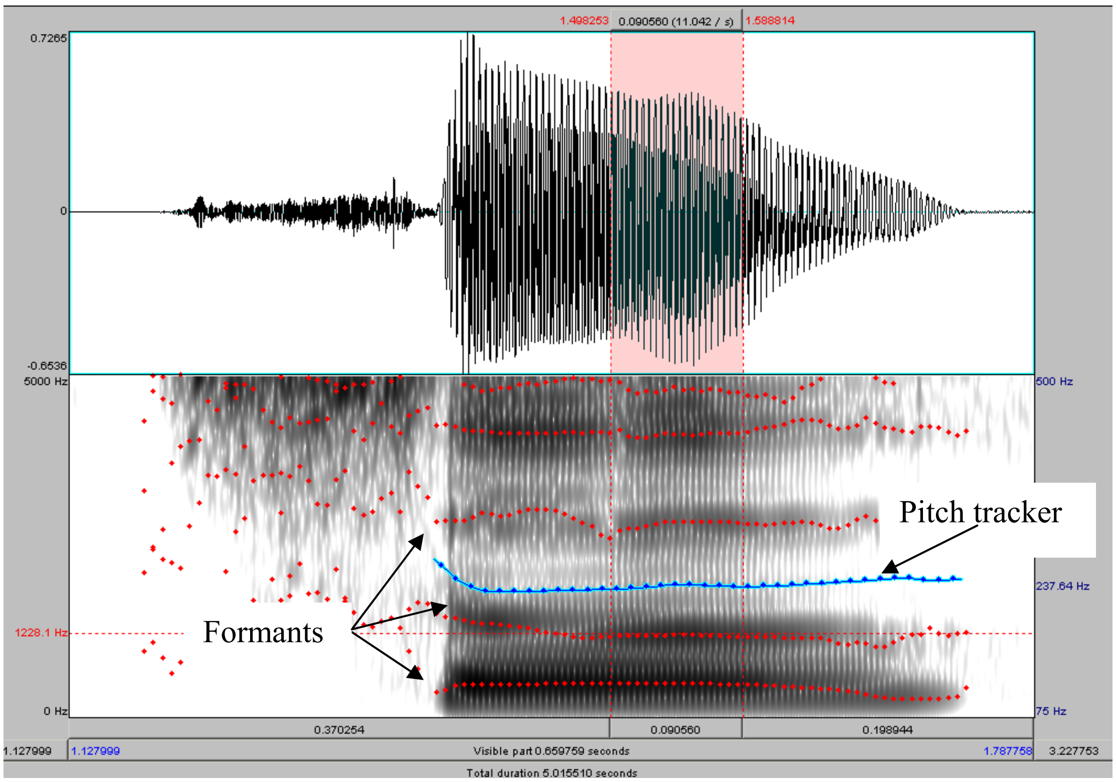


Figure 3.2: Steady state of the vowel [o] in Ifè *so* 'to attach', Speaker 4F. Pictured is the waveform and wideband spectrogram. Formant tracks are represented by dotted red lines, the pitch track by the blue line.

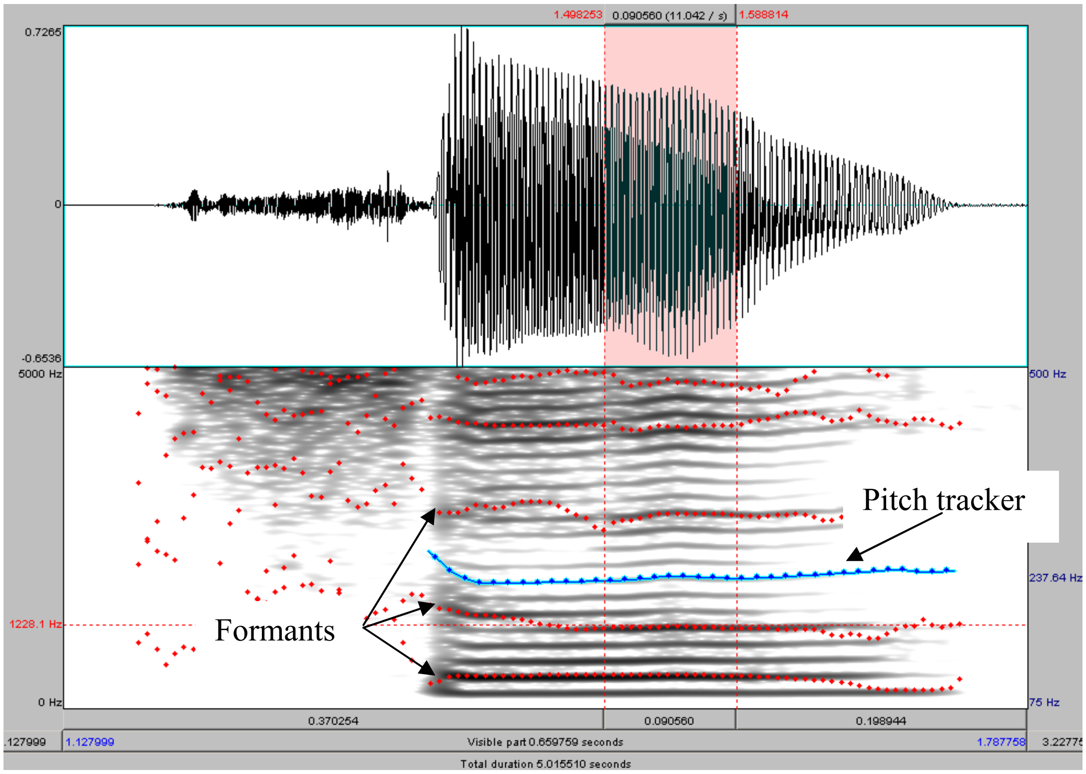


Figure 3.3: Steady state of the vowel [o] in Ifè *so* 'to attach', speaker 4F. Pictured is the waveform and narrowband spectrogram. Formant tracks are represented by dotted red lines, the pitch track by the blue line.

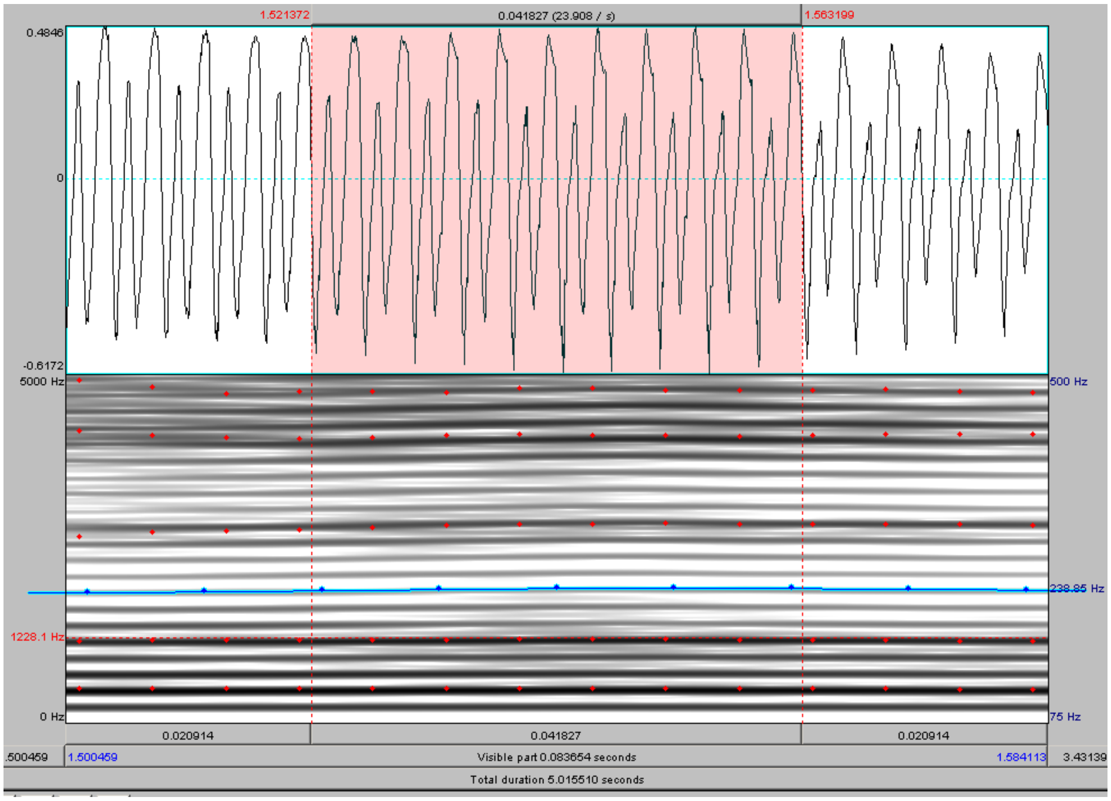


Figure 3.4: F1-F3 for formant analysis (vowel [o] in Ifè *so* ‘to attach’, speaker 4F). Five-ten pulses were selected from the middle of the steady state of the vowel.

The formant settings chosen for analysis were ones suggested in the documentation of the PRAAT program, namely a maximum formant Hz of 5000 for male speakers and 5500 for female speakers. Formant numbers were typically set to 5. This procedure worked well for most speakers. Occasionally, though, the filter needed finer tuning for certain speakers or tokens and was adjusted for either maximum formant Hz or for number of formants. However, since F1 appeared to be especially sensitive to changes number of formants, typically increasing in Hz value, every effort was made to keep the number of formants set to 5 for the F1 measure for greater consistency within the vowel system of any one speaker. This is particularly important for the 9 (10) vowel languages whose speakers tend to have overlapping F1 values for [-ATR] high and [+ATR] mid vowels.

3.3.4 F1 Bandwidth (B1)

One of the means of capturing spectral timbre differences between [+ATR] and [-ATR] vowels is measuring formant bandwidth. Hess (1992) was the first to implement a study of bandwidth (in particular, F1 bandwidth) for a language with [+ATR] vowel harmony. She had noted that the formants of [+ATR] vowels in Akan appeared narrower in wideband spectrograms than in their [-ATR] counterparts. Since bandwidth is largely predictable from formant frequency (Fant 1960), Hess compared vowels of differing ATR (/ɪ/ and /e/, /ʊ/ and /o/) which overlapped, or partially overlapped, in acoustic space. Results of her study indicate that while there is only a 10-11% difference in F1 frequency between /ɪ/ and /e/ and /ʊ/ and /o/, there is 33% difference in F1 bandwidth (B1) for the front vowels and a 66% difference in F1 bandwidth for the back vowels. Two one-way ANOVA were run for F1 and B1 and while results indicated that the differences in F1 for /ɪ/ and /e/ were highly significant, so were those for B1. Formant frequency and bandwidth however, were only moderately correlated, from which she concludes that differences in the location of F1 were not responsible for the differences in B1.

To understand the importance of her findings, I have reproduced her plot of the means of F1 frequency and F1 Bandwidth in Figure 3.5. This graph shows that [-ATR] vowels have higher frequencies and thus wider bandwidths than their [+ATR] counterparts. Moreover, we see the differences between the height two ([-ATR] high) and height three ([+ATR] mid) vowels: these vowels are indeed very close in F1, but widely separated in F1 bandwidth.

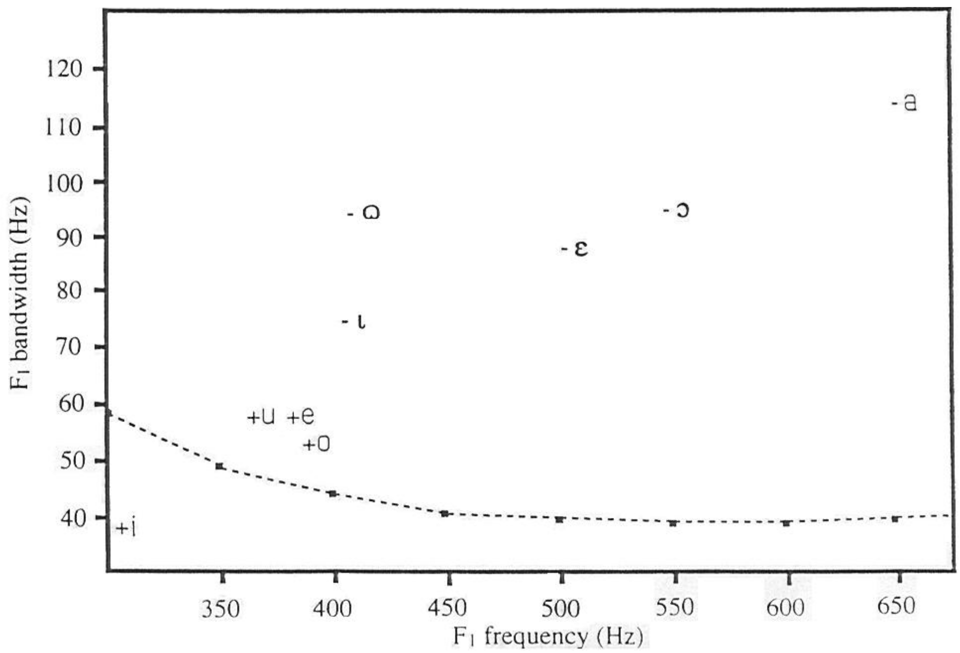


Figure 3.5: Mean F1 frequency vs. mean F1 Bandwidth with predicted B1 values based on Fant's (1972) formula for modeling vocal tract losses (Hess 1992).

In addition, this graph includes a dotted line which represents the predicted values of B1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract as shown in (30).

(30) $B_1 = 15(500/F_1)^2 + 20(F_1/500)^{1/2} + 5(F_1/500)^2(\text{Hz})$

Lower F1 frequencies should have the highest B1 frequencies with a gradual leveling off at higher F1 frequencies, due to cavity losses from wall vibration. In the case of the one Akan speaker, the mean B1 frequency of the [+ATR] high front vowel /i/ is much lower than the predicted value. Other [+ATR] vowels approach predicted values, while all [-ATR] vowels greatly exceed predicted values.

Hess also compares her findings on the one speaker of Akan with the data of Fujimura & Lindqvist (1971) on the bandwidths of Swedish vowels. Fujimura & Lindqvist conducted their experiment via the excitation of the vocal tract with closed glottis by an external sweep-tone. The averages of their results, reproduced in Figure 3.6, show curves similar to the one for Hess's predicted B1 values for Akan. Lower F1 values have greater dissipation, represented by higher bandwidths. Note that the F1 values for high front vowels for males (scattered around the solid line) range between 60 and 80 Hz, but between 80 and 90 Hz for females (scattered around the dotted line), with some values exceeding 100 Hz. While the B1 values for the lower frequencies of F1 for male speakers of Swedish compare roughly to those of the [+ATR] back and mid vowels for the Akan speaker, the values of B1 for /i/ are considerably higher. In addition, B1 values for vowels with F1 means above the 400 Hz range never surpass a 50 Hz average in the Swedish results. This differs greatly from the Akan speaker whose [-ATR] vowels with F1 values above 400 Hz have mean bandwidths of 75 to 110 Hz.

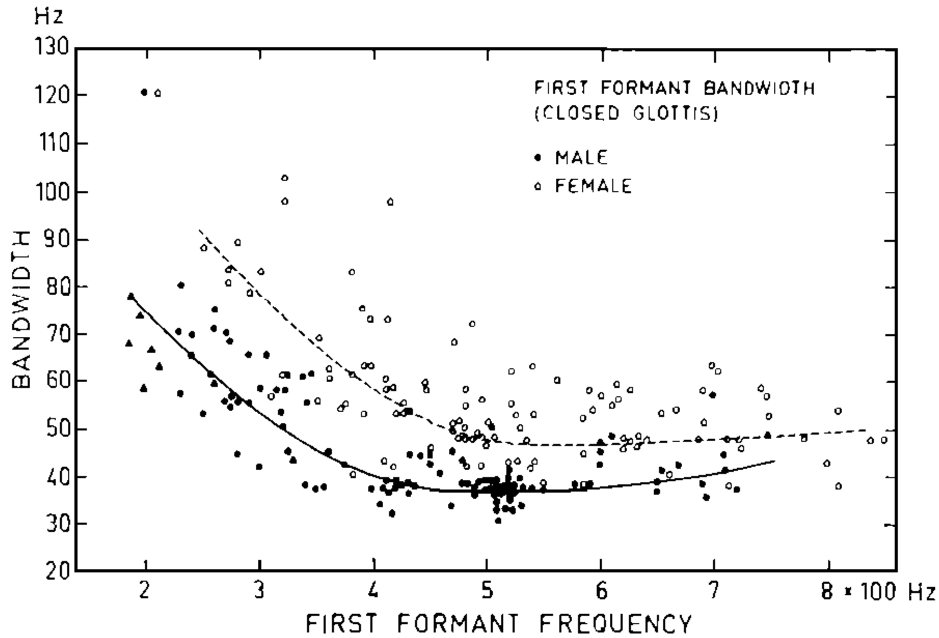


Figure 3.6: F1 Frequency versus B1 frequency for Swedish vowels (Fujimura & Lindqvist 1971)

Przezdziecki (2005) also conducted B1 measurements for the three variants of Yoruba in his study: Mọba, Standard Yoruba (SY) and Akurẹ. Mọba and SY have seven underlying and surface vowels with mid-vowel harmony, while Akurẹ has seven underlying and nine surface vowels with cross-height harmony seen only in its prefixes. The results for B1 means of the SY speaker's mid vowels show very little difference and were not statistically significant. The results for the Mọba speaker, however, mirror those of the Akan data: the B1 means for [-ATR] mid vowels are significantly higher than their [+ATR] counterparts. In fact, the spread between the B1 values for [+ATR] and [-ATR] mid vowels of this speaker is even greater than that of the Akan speaker: his [+ATR] vowels have lower bandwidths and his [-ATR] vowels have higher bandwidths than the Akan speaker. The results for the four Akurẹ speakers were mixed.

For three of the four speakers, [+ATR] /i/ and its [-ATR] allophone [ɪ] may be distinguished by bandwidth differences: the bandwidth of the [-ATR] vowel is significantly higher than the [+ATR] vowel. Two of the speakers also show the same pattern for the high back vowels. The mid vowels fare more poorly. With the exception of the front mid vowels of one speaker, none of the mid vowels pairs of any of the other speakers mirror the Hess results for Akan. Their mean B1 differences are either not statistically significant or pattern contra expectation, with [+ATR] vowels having higher B1 means than their [-ATR] counterparts. Note though that Przezdziecki does not completely follow the Hess model as he does not present any results of a baseline comparison for these speakers.

In the current study, F1 bandwidth was measured using the LPC method at the same point in the steady state of the vowel where F0 and harmonic differential measurements were obtained, as seen in Figure 3.1.

Because F1 bandwidth has been shown to be correlated with or largely predictable from changes in F1 frequency (though only mildly so in the Akan data as discussed above), some researchers have preferred to develop other techniques for measuring spectral timbre differences. One such technique involving a normalization process of the strongest harmonics associated with F1 and F2 is discussed in §3.3.5. Assuming Fant's empirically-derived formula for modeling the effects of vocal tract losses is normative, another possibility for evaluating observed B1 values would be to determine how best those values fit the predicted curve. Unfortunately, no known commercial statistical tool is capable of such an evaluation. Another possibility, though not as rigorous as a correlation curve, is to compare the observed B1 values to the B1 values predicted by the empirically-derived formula in (30) by subtracting predicted B1 from the observed B1 value - termed here *Delta B1* (ΔB1). The [ATR] pairs of Delta B1 can then be subjected to statistical analysis. Such an analysis can minimally tell us whether the means of the displacement of B1 from their predicted values within [ATR] pairs are statistically significantly different.

3.3.5 Normalized A1-A2 (a spectral flatness measurement)

In their perceptual study of the integration of tongue root position and vocal register in vowels, Kingston et al. (1997) hypothesize that so-called voice quality differences noted in African and Southeast Asian languages, as well as in English as tense or lax, covary with the advancement (or retraction) of the tongue root.[40] The claim is that as the voice is laxed, energy is increased in the first harmonic relative to higher harmonics at the same time that advancing the tongue root lowers F1. The opposite then may be said for the energy as the voice is tensed: it couples with higher F1 values. These two articulations, they claim, may integrate into another perceptual property they term spectral flatness, a term which references the general frequency range of the energy concentration in the spectrum of a vowel (Fulop et al. 1998). They tested these hypotheses with Garner-paradigm experiments which evaluate the interaction across a wide range of tense-lax voice qualities coupled with a narrow range of F1 values,

[40] Note that Kingston et al., like others, do not differentiate between voice quality and vocal register differences. The assumption being made here is that what the authors refer to as voice quality is better understood as vocal register.

discovering that listeners are sensitive to flatness at the extremes of the voice quality continuum but not in its middle region.

Because F1 bandwidth has been shown to be correlated with or largely predictable from changes in F1 frequency (though only mildly so in the Akan data as discussed above), some researchers have preferred to develop other techniques for measuring spectral timbre differences. For example, Fulop, et al. (1997) in their study of Degema vowels pursue the notion of spectral flatness by developing a technique which compares a normalized measure of the relative formant intensity of the first two formants with their observed values (See also Guion et al. 2004). Specifically, the amplitude (in dB) of the harmonic closest to F2 (A2) is subtracted from the amplitude of the harmonic closest to F1 (A1) and the result is then compared to a baseline or normalized A1-A2 value that is derived via the formulas presented in (31-33) and discussed below.

(31)

$$dB(f) = 20\log_{10} \frac{F^2 + (b/2)^2}{\sqrt{(f-F)^2 + (b/2)^2} \times \sqrt{(f+F)^2 + (b/2)^2}}$$

(32)

$$dB(f) = 0.72(f/492)2 + 0.0033(f/492)^4$$

(33)

$$dB(f) = g\left(-20\log_{10}\left(2\frac{f/100}{1 + (f/100)^2}\right)\right)$$

Each of these formulas models a contribution of the energy produced in the vocal tract to the spectrum of a vowel: (31), the contribution of the first three formants to F1 (or F2), (32), the contribution of the formants above F3, and (33), the contribution of the effects of lip radiation and glottal pulse shape. The addition of these five contributions is seen in combined curve of 3.7 (from Fulop et al. 1998).

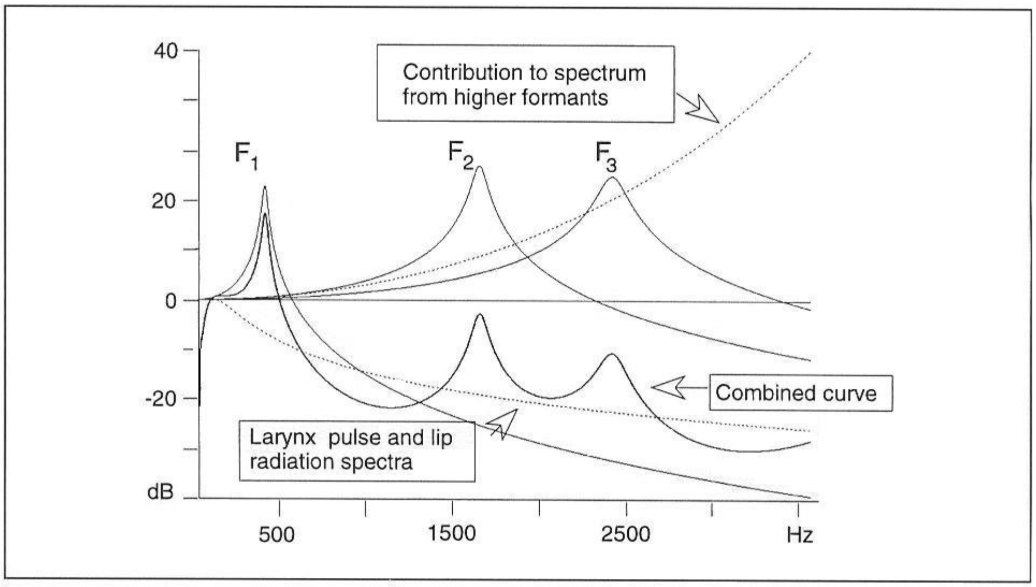


Figure 3.7: Curves representing F1, F2, F3, and the contribution of higher formants, larynx pulse and lip radiation, plus the combined curve, the sum of the other curves, representing the vowel spectrum (Fulop et al. 1998:90)

The formula in (31) models the contribution of the first three formants seen in Figure 3.7 which when added together form the combined curve. In this formula, f = the measured frequency of interest (F1 or F2); F = the measured formant frequency (F1, F2 or F3); b = formant bandwidth and is a number held as a constant for each of the first three formants (30 Hz for F1, 80 Hz for F2 and 150 Hz for F3). The contributions of F1, F2 and F3 are then added together, and to these the contribution of the upper dotted line representing the higher formants in Figure 3.7, are added using formula (32). Formula (32) assumes a vocal tract length of 17.5 cm with an F1 of 492 Hz for a neutral vowel (viz. Fant, 1960:50). Finally, the contribution of the larynx pulse and lip radiation, represented by the lower dotted line in Figure 3.7 is also added in via formula (33). The variable *g* represents phonation type and is set to 1.0 to assume modal voice.

The F1, F2, and F3 measurements, as well as the spectral slice taken for the amplitudes of F1 and F2 were obtained at the same point in the steady state of the vowel as F0 and B1, as seen in Figure 3.1. Figure 3.8 shows the spectral slice of Figure 3.1 for one token of the vowel [o] as spoken by Ifè speaker 4F. In this case, the harmonic closest to F1 is H2 whose amplitude is the number in blue circled in the upper right hand corner of the figure (55.5 dB). The harmonic closest to F2 in this token is H5. Its amplitude (44.3 dB) is found in red and circled to the left of the red horizontal line. The observed values of A1, A2, F1, F2 and F3, as well as the formant bandwidth constants (30 Hz for F1, 80 Hz for F2 and 150 Hz for F3) were entered into a MS Excel worksheet and plugged into formulas (23)-(25). The difference between modeled A1-A2 was then subtracted from the measured A1-A2 in preparation for statistical analysis. See §4.4 for further detail.

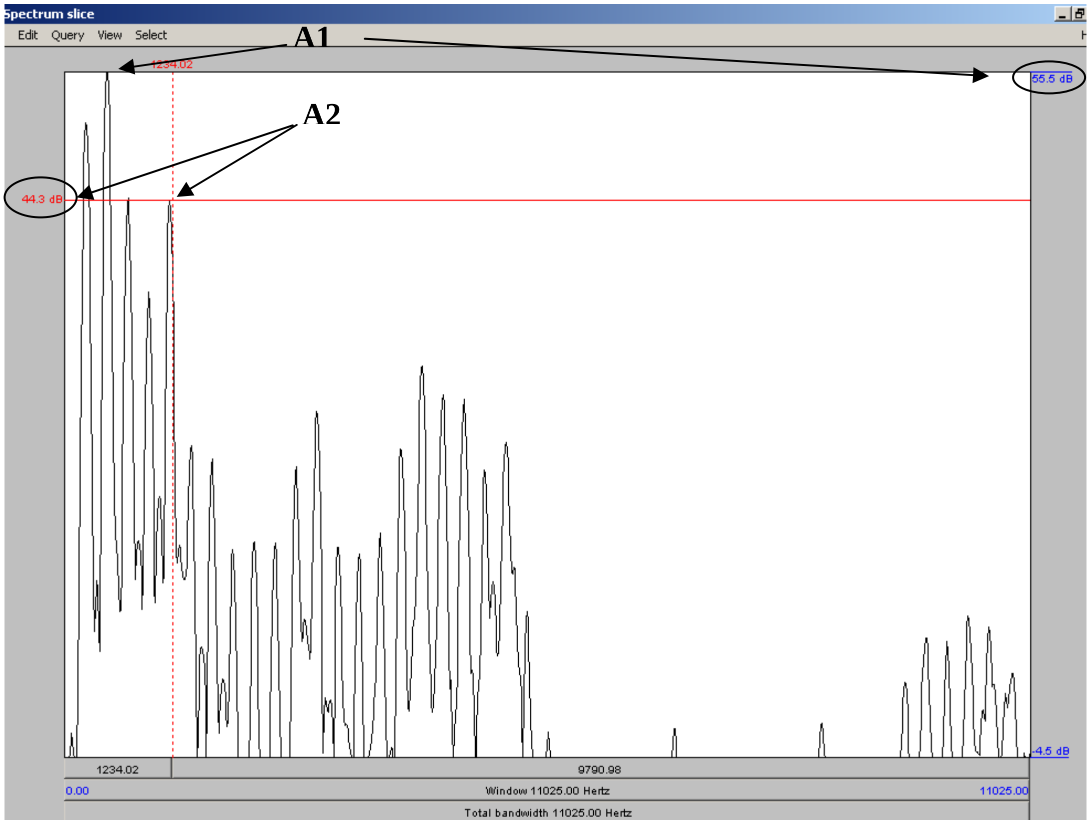


Figure 3.8: Spectral slice for the measurement of amplitude of the harmonic most closely corresponding to F1 (A1) and to F2 (A2) (vowel [o] in Ifè *so* 'to attach', speaker 4F)

3.3.6 Center of Gravity

Put simply, the spectral center of gravity of a sound is the measure of the mean of the frequencies of the sound's spectrum over a specific domain. Center of gravity, also known as spectral mean, measurements have been used for some time in the acoustic study of fricatives (e.g. Forrest et al. 1988, Zsiga 1993, and Jongman et al. 2000 for English; Svantesson 1986 for Mandarin Chinese; Norlin 1983 for Cairene Arabic; and Gordon et al. 2002 for Aleut, Apache, Chickasaw, Gaelic, Hupa, Montana Salish and Toda). Center of gravity has also been observed in studies of synthetic vowel perception (Delattre et al. 1952, Bedrov et al. 1976, and Chistovich & Lublinskaya 1979, among others). Such studies are concerned with a so-called center of gravity 'effect', to the gross maxima or to the formant cluster location, and focus on changes in vowel quality. Of particular interest here is the center of gravity effect which refers to a resulting perceptual difference when two formant peaks, close in frequency, have their amplitude ratio changed. Delattre et al. (1952), for example, discovered that variation in the amplitude of F1 of front vowels does not affect vowel quality; rather, it results in perceptually duller or sharper timbre. This is precisely the kind of difference that is expected to be perceived in vowels which overlap in acoustic space but which have vocal register differences associated with them. This study extends these expectations then to [ATR] harmony pairs.

Center of gravity measurements of vowels in this study pattern are inspired by the recent work of Edmondson and Esling (2006) in their categorization of the valves of the throat by means of laryngoscopic observation. Three of the valves of larynx are seen in Figure 3.9 from Esling & Harris 2005 (as reproduced in Edmondson & Esling 2006a:163). Of particular interest to this study is Valve 3 which Edmondson and Esling show to be an integral part of the production of [-ATR] vowels in Kabiye (Gur)[41]. According to Edmondson and Esling, Valve 3 involves the "sphincteric compression of the arytenoids and aryepiglottic folds forwards and upwards by means of the thryoarytenoid muscle complex" (page 159). The arytenoid cartilages and aryepiglottic folds may be seen in the top half of Figure 3.9.

[41] Other valves are also involved in the production of Kabiye vowels, but they are not of interest at this point in our discussion.

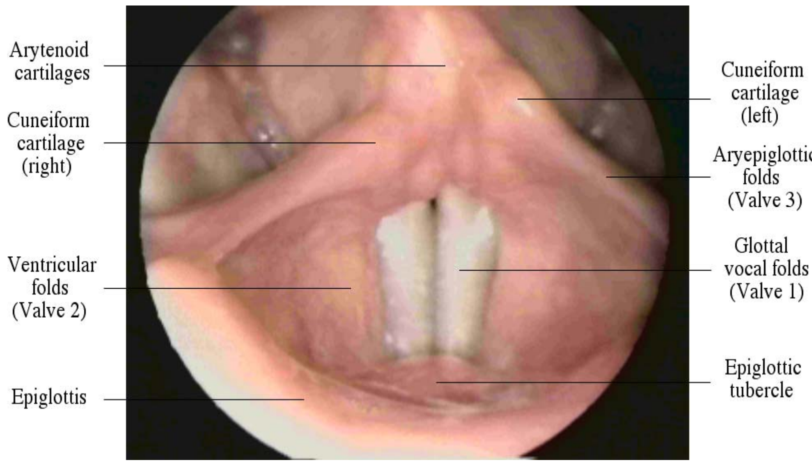
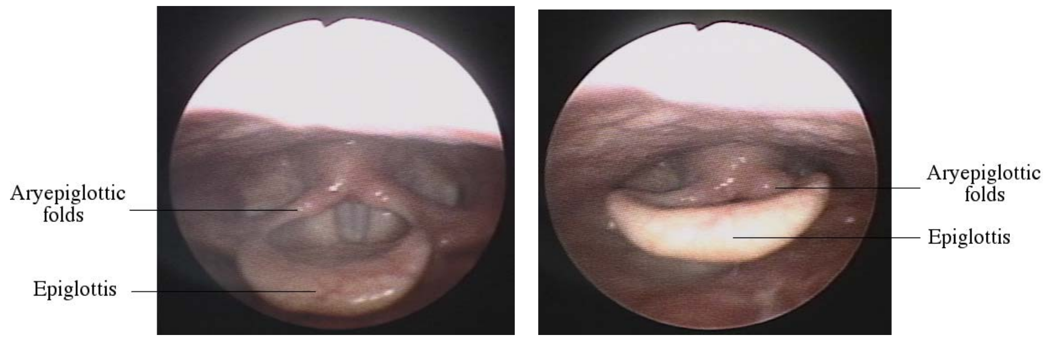


Figure 3.9: Three valves of the larynx (Esling & Harris 2005 as reproduced in Edmondson & Esling 2006a:163)

As an example of an articulation involving Valve 3, consider the difference between the position of the arytenoids and aryepiglottic folds in relation to the epiglottis for [+ATR] /u/ and [-ATR] /ʊ/ from Edmondson and Esling's data of Kabiye. The aryepiglottic folds are greatly compacted onto the epiglottis in the [-ATR] example of Figure 3.10 as opposed to its [+ATR] counterpart.[42] Similar results are duplicated for the rest of the [ATR] pairs presented in their work on Kabiye.

[42] While the images of the larynx produced via laryngoscopy greatly elucidate the articulation of [ATR] in Kabiye, what is not readily apparent from the images is the presence or absence of any vertical displacement of the larynx.



[+ATR] [tú] ‘elephant’ vs. [tʊ́] ‘bee’ [-ATR]

Figure 3.10: The state of valve 3 in Kabiye [+ATR] /u/ and [-ATR] /ʊ/
(Edmondson & Esling 2006)

According to Edmondson & Esling (2006b), if there is a constriction for [-ATR] vowels at Valve 3, then this constriction should have an acoustic reflex in the wave profile. They suggest that center of gravity (of the entire frequency range) is a measure potentially sensitive enough to stricture to produce significant results between [+ATR] and [-ATR] vowels. The prediction is that [-ATR] vowels will have a significantly higher center of gravity than their [+ATR] counterparts. In a 2008 manuscript, Edmondson, Padayodi, Silva and Esling provide evidence that [-ATR] vowels in Kabiye do in fact have significantly higher center of gravity means than [+ATR] vowels. Additionally, in a pilot study of Foodo, presented in Anderson 2007, it was suggested that center of gravity means were significant in distinguishing phonological height. The current study reconsiders the Foodo center of gravity data as a part of the profile of distinguishing [ATR] pairs in Foodo.

The center of gravity for a vowel was calculated within PRAAT using the program’s default settings, where *p* (power) is set to 2. The formula used in calculating the center of gravity is seen in (34a) where *S*(*f*) is the complex spectrum and *f* is the frequency. This is divided by the “energy” formula in (34b) where, again, *p* = power. The center of gravity, therefore, is the mean of *f* over the entire domain of the frequency, divided by $|S(f)|^p$. *p* is set to 2 for the weighting to be done by the power spectrum.

(34a) $\int_0^\infty f\,|S(f)|^p\,df$

(34b) $\int_0^\infty |S(f)|^p\,df$

Note that the calculation of center of gravity includes the absolute value of the complex (i.e. imaginary) function *S(f)* guaranteeing that when squared no negative values are produced. Thus, all differential contributions contribute to the sum.

When selecting the portion of a vowel to be measured for center of gravity, care must be taken to avoid “boundary or transition effects,” that is, the influence of onset or coda consonants or phrase final effects such as breathiness (viz. Cooper & Sorenson 1981). Figure 3.11 illustrates the selection of the portion of a vowel in an open syllable while Figure 3.12 illustrates a vowel in between two consonants. Figure 3.11 is the same vowel token from Ifè seen in earlier examples. Figure 3.12 is an example from one of the female Foodo speakers. Approximately two-thirds to three-quarters of the vowel that included the steady state were selected for the center of gravity measurement. The beginning of the selection started 20-40 ms from the onset of vowel voicing, far enough away from the consonantal transition seen in both the waveform as the “tadpole head” in Figure 3.11 and the narrowband spectrogram as blurry harmonics in both figures. In both open and closed syllables, the end of the selection was made at the point where the lower formants begin to show transitional effects of either a following consonant, as seen in the "tadpole head" of the waveform in Figure 3.12 and lowering of F2 as it transitions into the alveolar fricative or by the sudden damping of higher harmonics between F2 and F3 due to phrase final breathiness as may be seen in Figure 3.11.

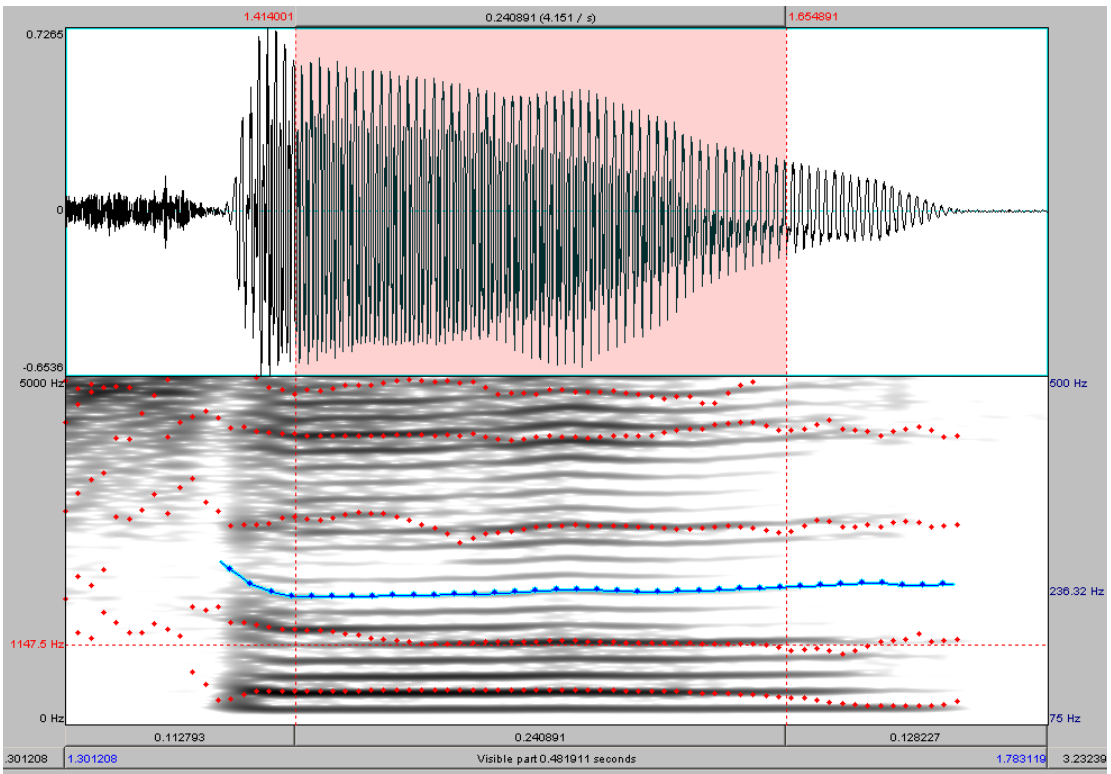


Figure 3.11: Center of gravity of a vowel in an open (phrase final) syllable (vowel [o] in Ifè *so* 'to attach', speaker 4F)

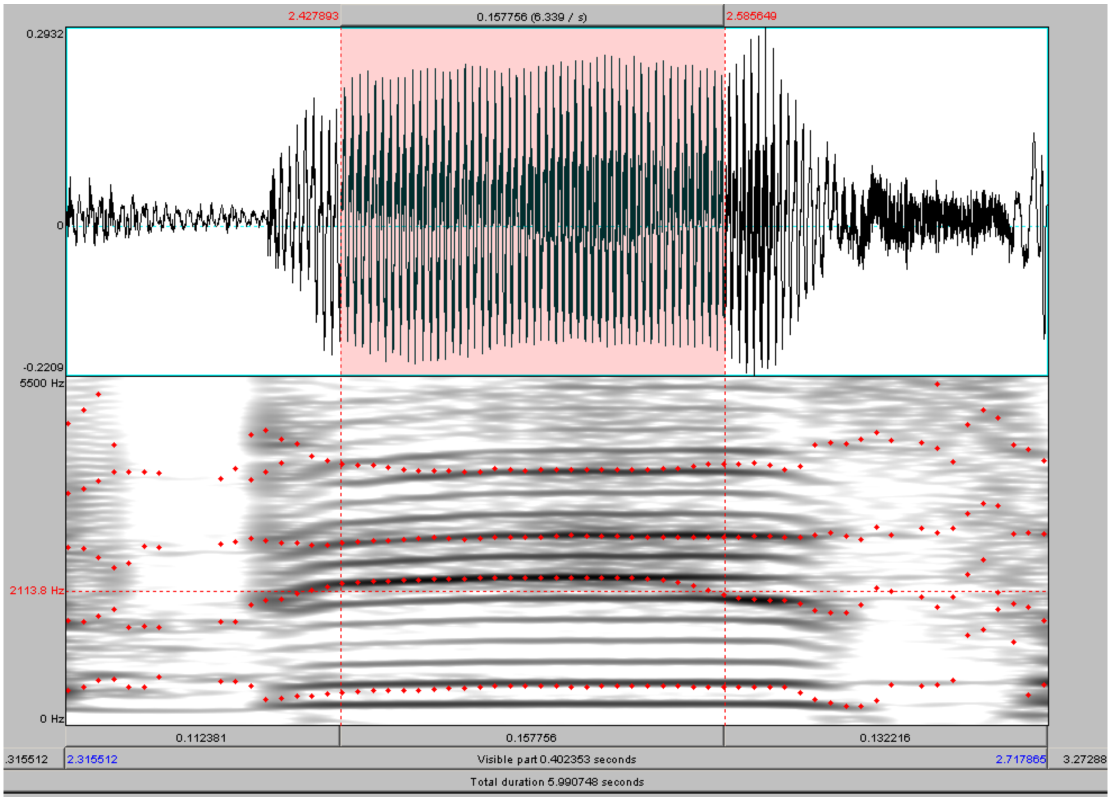
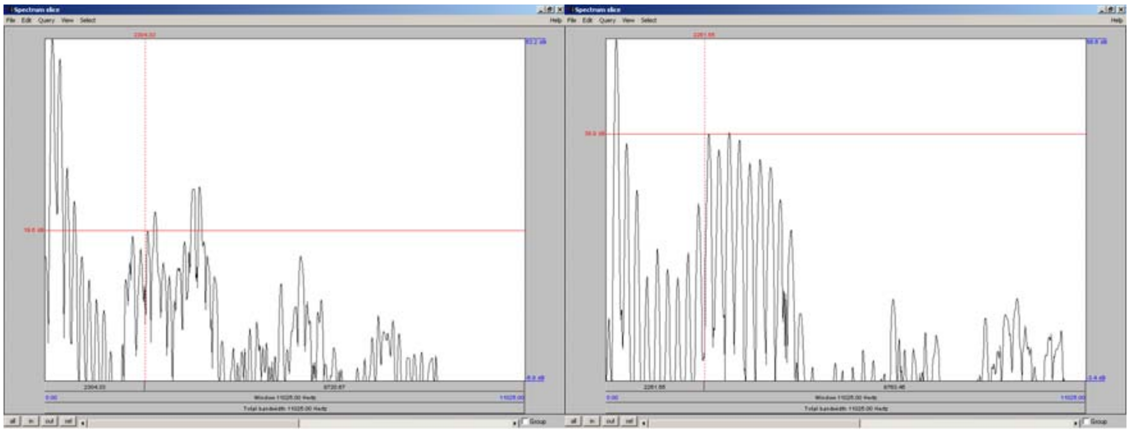


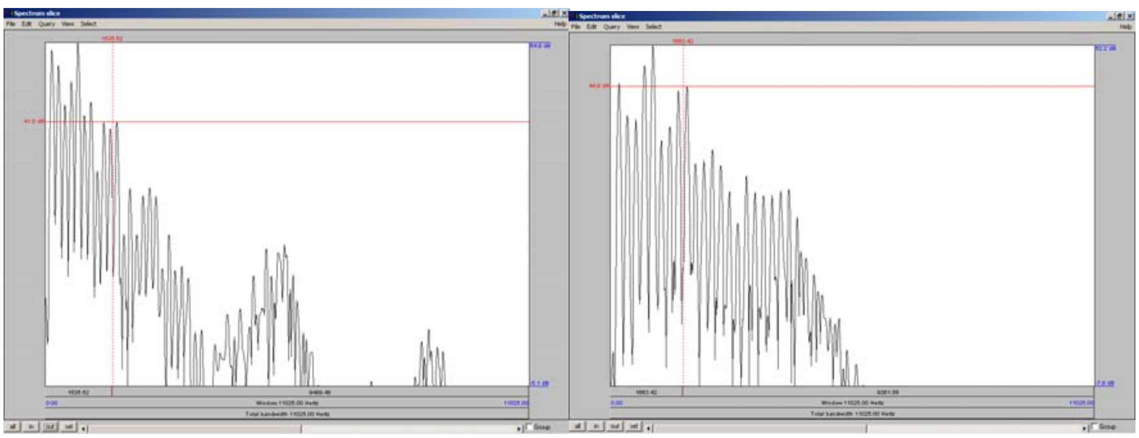
Figure 3.12: Center of gravity of a vowel in a closed syllable
(vowel [ɪ] in Foodo *dɪɪsa* ‘to ask’, speaker 4F)

While this study considers the center of gravity of vowels over their entire spectral frequency domain, and thus is concerned with statistical significance of center of gravity means between [ATR] pairs, it takes into account the fact that for some speakers, the spectral mean of any given vowel may lie below the harmonic most closely associated with F1. Figures 3.13 and 3.14 illustrate this phenomenon. In both figures, a spectrum slice of a vowel was generated at its steady state for (a) one male speaker and (b) one female speaker of Mbosi. Figure 3.13 illustrates a token of [i] for both speakers while Figure 3.14 illustrate a token of [ɑ]. The intersecting horizontal and vertical lines mark F2 and the harmonic closest to it.



(a) (b)

Figure 3.13: Spectrum slice of [i] for two Mbosi speakers
(a) one male and(b) one female



(a) (b)

Figure 3.14: Spectrum slice of [ɑ] for two Mbosi speakers
(a) one male and (b) one female

Two pertinent observations of the harmonic structure of the vowels for each speaker may be noted. First, the harmonics above the harmonic associated with F2 in both figures remain relatively strong for (b) the female speaker in comparison to those of (a) the male speaker; second, there are one or more strong harmonics below F1 in the case of the male speaker relative to the female speaker. In Figure 3.13 (a) the F1 value lies close to H2 at 300 Hz, while in (b), F1 aligns more closely with H1 (=F0) at 264

Hz. The center of gravity for these two vowels is 265 Hz and 600 Hz, respectively. The relative strength of the harmonics at and above F2 in (b) skew the center of gravity towards F2, while the relative strength of the lower harmonics in (a) skew center of gravity to a point below F1.

Similar sorts of observations may be made for Figure 3.14 where the F1 aligns with H5 for both speakers - 736 Hz for (a) and 895 Hz for (b). Center of gravity for the male speaker's [ɑ] is 545 Hz, but 1027 Hz for the female speaker. It would appear that for some speakers, stronger lower frequencies and/or weaker higher frequencies may well cause center of gravity to hover near or even below the F1 frequency. Since this study is also testing the assumptions of Edmondson & Esling 2006b concerning a potential constriction at Valve 3 in the larynx, as well as comparing its results to those of Edmondson, Padayodi, Silva and Esling 2008 for Kabiye, it is deemed important not just to determine whether center of gravity means between [ATR] pairs are statistically significantly different, but to evaluate the relative importance of those findings. This is done within this study by comparing center of gravities *par rapport à* F1 values via a simple t-test once the center of gravity - F1 differential is calculated.

CHAPTER 4

RESULTS

4.1 Introduction

In this chapter, the results of the four major acoustic measures conducted in each language are presented in turn. The chapter is organized as follows: Section 4.2 presents the results of the analysis of the first and second formants (F1 and F2) for each speaker by language; Section 4.3 examines the results of the first formant bandwidth (B1) measurements; Section 4.4 reviews the results of Normalized A1-A2, a measure of spectral flatness; while section 4.5 presents the outcome of the center of gravity measurements.

The statistical tool used for the analyses presented in this chapter is SPSS 14 software. For each language, and for individuals within the sample, a series of models to determine statistical significance of mean differences of [ATR] harmony pairs and cross-height harmony pairs (if relevant) have been conducted. These include (in most cases) univariate ANOVA for [ATR] pairs, one-way ANOVA for vowel qualities, and occasionally t-tests.

4.2 Formant Analysis

This section communicates the results of the formant analysis for each of the eleven languages featured in this study. For each language, the following are presented:

- F1 vs. F2 formant charts for each speaker,

- the results of the ANOVA, and
- tables of F1 and F2 means for harmonic pairs with highlighting of the non-significant means.

The following are presented in each formant plot display:

- a scatter plot with individual F1 vs. F2 data points represented by small IPA characters,
- the mean of each vowel represented by large circled IPA characters, and
- a color display for gender of the speaker (blue for male, red for female).

Unless otherwise indicated, the level of statistical significance has been set at α =95%, such that p-values are evaluated at the 0.05 threshold.

4.2.1 Foodo

Figures 4.1-4.4 are the F1 vs. F2 formant plots for the four Foodo speakers. These same plots appear in a working paper (Anderson 2007), the focus of which differs slightly from the current study. As noted in Anderson 2007, visual inspection of the formant plots reveals no obvious overlap of F1 for the [ATR] harmony pairs. F2 values, on the other hand, overlap for at least one pair of the vowels in all speakers. In addition, [-ATR] high vowels (height 2), [ɪ ʊ], overlap for F1 considerably with [+ATR] mid vowels (height 3), [e o], respectively.

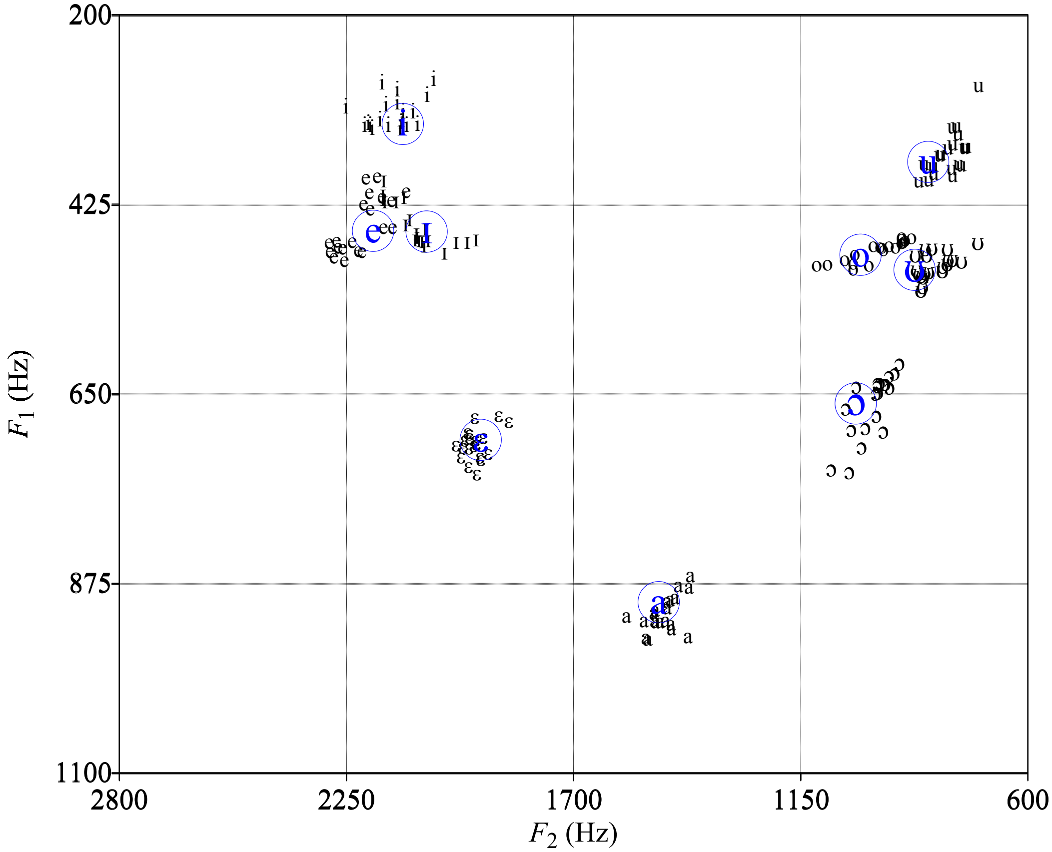


Figure 4.1: F1 vs. F2 vowel formant chart for Foodo speaker 1, male (1M-K)

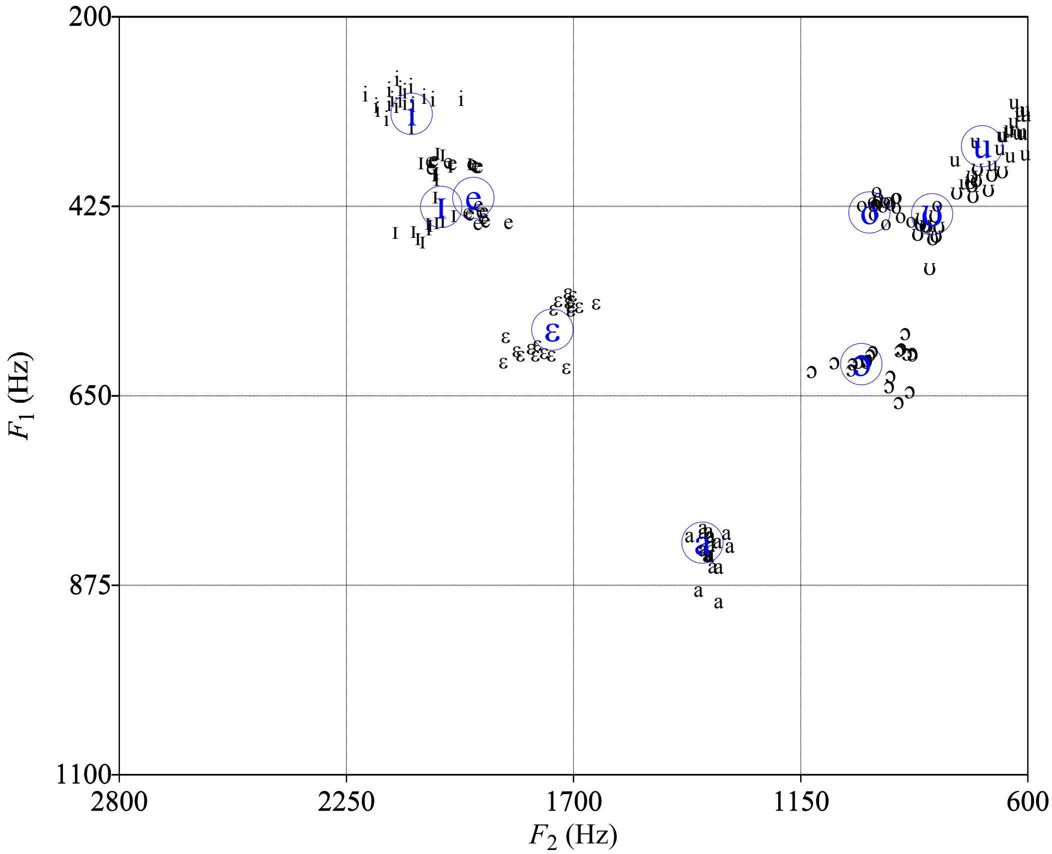


Figure 4.2: F1 vs. F2 vowel formant chart for Foodo speaker 2, male (2M-Z)

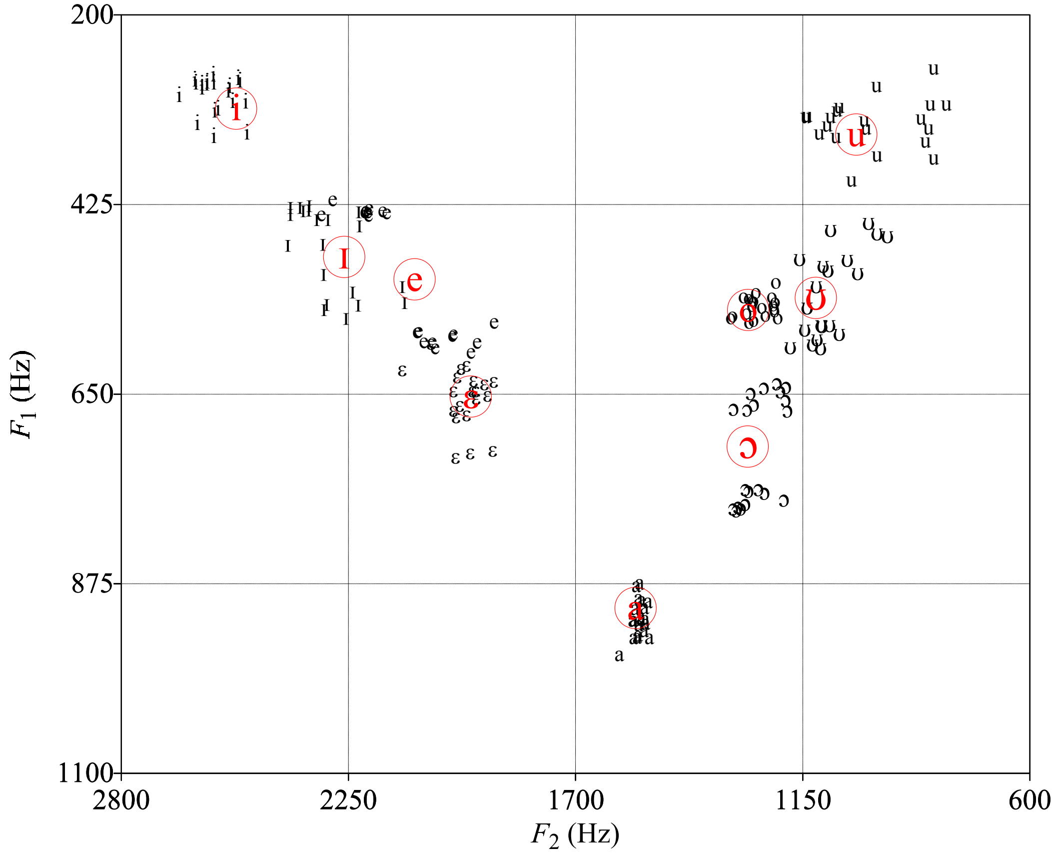


Figure 4.3: F1 vs. F2 vowel formant chart for Foodo speaker 3, female (3F-B)

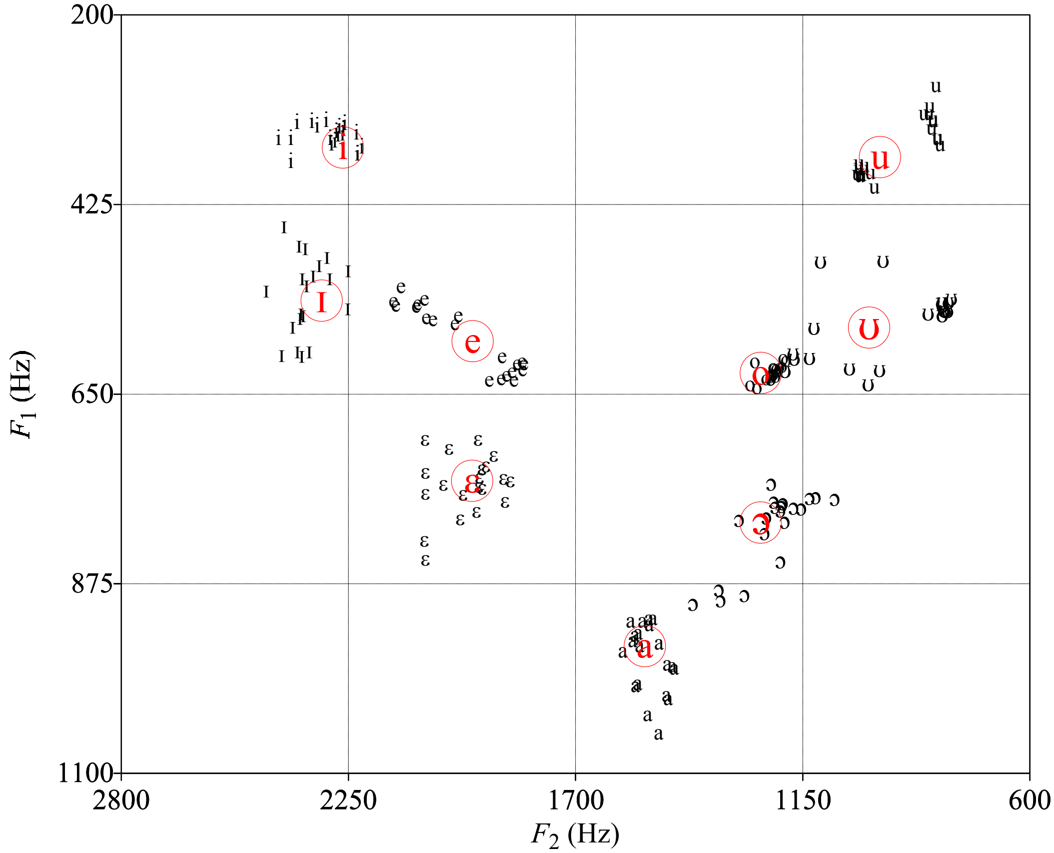


Figure 4.4: F1 vs. F2 vowel formant chart for Foodo speaker 4, female (4F-A)

First, the F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, /e ɛ/, /o ɔ/ and /u ʊ/) [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). Since [ATR] interacts significantly with both Gender and Vowel Group [$F(3,624)=19.46$, $p=0.000$[43]], four separate univariate ANOVA were run, one for each speaker with Vowel Group and [ATR] value as factors. The level of significance is set at 0.0125 for four speakers (i.e., dividing the established p-level value of 0.05 by four, thereby accounting for the fact that the data

[43] Note that SPSS reports results of p<0.001 as p=0.000.

have been divided into four separate analyses). For the two males, [ATR] interacts significantly with Vowel Group [1M-K $F(3,152)=57.01$ $p=0.000$; 2M-Z $F(3,152)=30.03$ $p=0.000$], but not for the two females [3F-B $F(3,152)=2.57$; 4F-A $F(3,152)=1.97$]. For each of the females, however, the overall effect of [ATR] is significant [$F(1,152)=543.68$ $p=0.000$ and $F(1,152)=1104.99$ $p=0.000$]. For both male and female speakers, [+ATR] vowels have significantly lower F1 values than their [-ATR] counterparts, but the effect is not consistent across vowel groups for the male speakers.

In order to investigate cross-height pairs [ɪ e] and [ʊ o], the F1 values of all the vowels were submitted to one-way ANOVA with F1 as the dependent variable and vowel quality (i ɪ e ɛ a ɔ o ʊ u) as the independent factor. This model was run for all of the speakers as a group (significance level set to 0.05) as well as for each speaker individually (using the adjusted value of 0.0125 for four speakers). The mean F1 values are summarized in Table 4.1, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.1: Foodo F1 Mean Values by Vowel Group for Each Speaker

Superscript numbers indicate cross-height vowel means which are not significant

Vowel Group	Vowel Quality	Pooled Data	1M-K	2M-Z	3F-B	4F-A
i	i [+ATR]	328	330	316	311	357
	ɪ [-ATR]	477[1]	458[1]	426[1]	487[1]	539
e	e [+ATR]	493[1]	457[1]	416[1]	514[1]	587
	ɛ [-ATR]	671	705	572	653	753
ɑ	ɑ [-ATR]	894	898	825	904	949
o	o [+ATR]	523[2]	485[2]	433[1]	550[2]	625
	ɔ [-ATR]	697	662	613	712	802
u	u [+ATR]	360	375	354	342	369
	ʊ [-ATR]	493[2]	503[2]	435[1]	514[2]	571

The main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled $F(8,711) = 641.84$, 1M-K $F(8,171) = 1182.9$; 2M-Z $F(8,171) = 770.1$; 3F-B $F(8,171) = 353.6$; 4F-E $F(8,171) = 611.9$]. In every case, SPSS reports p=0.000. As expected, the model confirms that the mean differences for F1 between each [ATR] pair are also statistically significant. F1 means for [+ATR] vowels are always significantly lower than their [-ATR] counterparts. The mean differences for cross-height vowel pairs [ɪ e] and [ʊ o], however, are not significant (as noted by superscript numbers 1 and 2 respectively) for three of the four speakers (1M-K, 2M-Z, 3F-B), as well as for the speakers combined within the overall model. Note that for speaker 2M-Z, the statistical model indicates no statistically significant differences among the four height 2 and height 3 vowels; therefore their means are marked with superscript 1 only.

Cross-height pairs [ɪ e] and [ʊ o] when submitted to separate ANOVA for all speakers and the individual speakers largely confirm the results of the overall model. As seen in Table 4.2, the differences in F1 mean values for these vowel pairs of speaker 4F-A are still statistically significant. In addition, the difference in mean values for the back pair, [ʊ o], of speaker 1M-K is significant. In all other cases, F1 mean differences fail to distinguish the two vowels in both pairs.

Table 4.2: F1 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Foodo

Shaded cells indicate mean differences are not significant.
Where F1 mean differences are significant, $p = 0.000$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,158)=2.09$	$F(1,158)=1.27$
1M-K	$F(1,38)= 0.01$	$F(1,38)=18.02$
2M-Z	$F(1,38)= 0.98$	$F(1,38)= 0.065$
3F-B	$F(1,38)= 1.78$	$F(1,38)= 1.56$
4F-A	$F(1,38)= 13.6$	$F(1,38)= 33.89$

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). As with the results for F1, [ATR] interacts significantly with both Gender and Vowel Group [$F(3,624)=10.73$ $p=0.000$]. The four separate univariate ANOVA yield mixed results. For the males and one of the females, [ATR] interacts significantly with Vowel Group [1M-K $F(3,624)=10.73$, 2M-Z $F(3,152)=66.04$, 3F-B $F(3,152)=66.04$] with $p=0.000$.

For the last female, 4F-A, neither [ATR] and Vowel Group nor the main effect of [ATR] are significant ([$F(3,152)=.813$] and [$F(1,152)=2.25$]). Vowel Group, however, is highly significant [$F(3,152)=2065.22$, $p=0.000$]. These results suggest that the [ATR] harmony pairs may not be consistently distinguished by F2 differences across speakers.

The one-way ANOVA sheds further light on the differences in speaker behavior. As with the F1 ANOVA, F2 is the dependent variable and vowel quality is the independent factor. These results are summarized in Table 4.3. As with F1, the main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled $F(8,711)=641.83$, 1M-K $F(8,171) = 2992.5$, 2M-Z $F(8,171) = 2474.7$, 3F-B $F(8,171) = 1274$, 4F-A $F(8,171) = 856.1$, all $p=0.000$]. Unlike F1, F2 does not prove to be a strong indicator of [ATR] between the vowel pairs, failing to distinguish mid back vowels /o ɔ/ for all four speakers, and failing to distinguish any of the vowel pairs for speaker 4F-A.

Table 4.3: Foodo F2 Mean Values by Vowel Pair for Each Speaker

Shaded cells within vowel groups indicate mean values which do not exhibit a statistically significant difference.[44]

Vowel Group	Vowel Quality	Pooled Data	1M-K	2M-Z	3F-B	4F-A
i	i [+ATR]	2247	2113	2092	2522	2263
	ɪ [-ATR]	2163	2055	2020	2260	2315
e	e [+ATR]	2042	2185	1942	2090	1949
	ɛ [-ATR]	1895	1924	1751	1954	1951
ɑ	ɑ [-ATR]	1492	1494	1388	1554	1532
o	o [+ATR]	1130	1005	984	1282	1252
	ɔ [-ATR]	1139	1016	1003	1283	1251
u	u [+ATR]	884	831	711	1020	963
	ʊ [-ATR]	953	874	832	1118	989

Cross-height pairs, [ɪ e] and [ʊ o], however, are distinguished by F2 mean differences. One-way ANOVA for all speakers, as well as for each speaker, (summarized in Table 4.4) yield statistically significant results. In all cases, p=0.000.

Table 4.4: F2 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Foodo

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,158)=31.46$	$F(1,158)=61.99$
1M-K	$F(1,38)= 51.36$	$F(1,38)=62.26$
2M-Z	$F(1,38)= 31.77$	$F(1,38)= 85.38$
3F-B	$F(1,38)= 30.92$	$F(1,38)= 115.81$
4F-A	$F(1,38)= 183.14$	$F(1,38)= 63.19$

[44] Differences in shading, unless otherwise indicated, are meant only as a visual aid for the reader.

4.2.2 Ikposo

Figures 4.5-4.9 are the F1 vs. F2 formant plots for the five Ikposo speakers of this study. Visually, Ikposo presents a different picture of acoustic vowel space than Foodo. There are some similarities between the back vowels, especially among the women's speech represented in these two datasets, but overall there is much more crowding of acoustic space in the lower frequencies in Ikposo. Notably, there is less of a difference in the values of F1 for high vowels. We will return to this observation in the next chapter on the acoustic summaries of each language. For the moment it is important to note that this crowding of the lower frequencies was first noted in Anderson 1999, where a different set of data for speaker 1M-J were presented. In those results, 1M-J's high front vowels overlapped for F1. Much was made of this fact in Anderson 2003. The current results (seen in Figure 4.5) show clearly that [i] and [ɪ] do not overlap for F1, suggesting that there was insufficient sampling in the earlier study. The earlier study and this current study, however, do show the same reversal of height 2 and 3 in back vowels for this speaker, with [+ATR] [o] sitting higher in acoustic space than [-ATR] [ʊ].

The F1 values of height 2 and 3 vowels tend to overlap in Ikposo, though to a lesser degree than Foodo. This overlap is most noticeable in the back vowels. There also appears to be considerable overlap of F2 for the [ATR] harmony pairs across speakers.

Finally, for two of the speakers, 1M-J and 5F-R, [+ATR] low vowel [ə] occupies space parallel to that of [ɛ].[45]

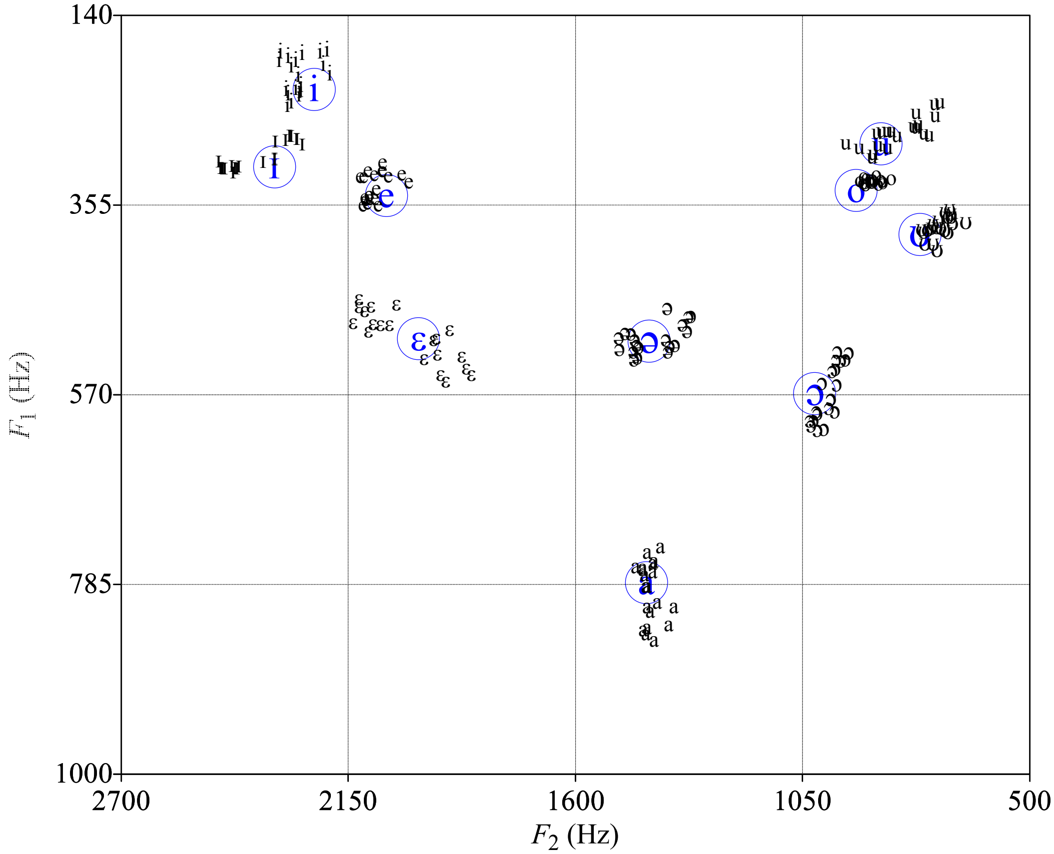


Figure 4.5: F1 vs. F2 vowel formant chart for Ikposo speaker 1, male (1M-J)

[45] These two speakers are siblings who grew up in the same village.

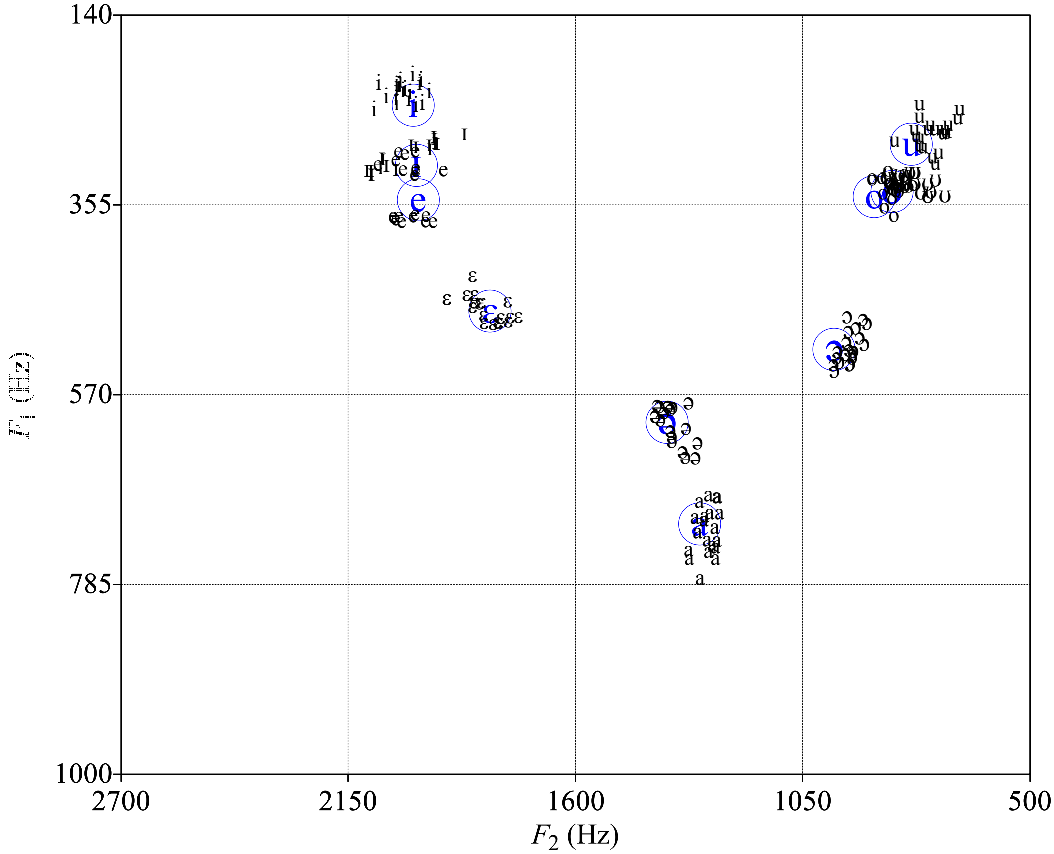


Figure 4.6: F1 vs. F2 vowel formant chart for Ikposo speaker 2, male (2M-Jo)

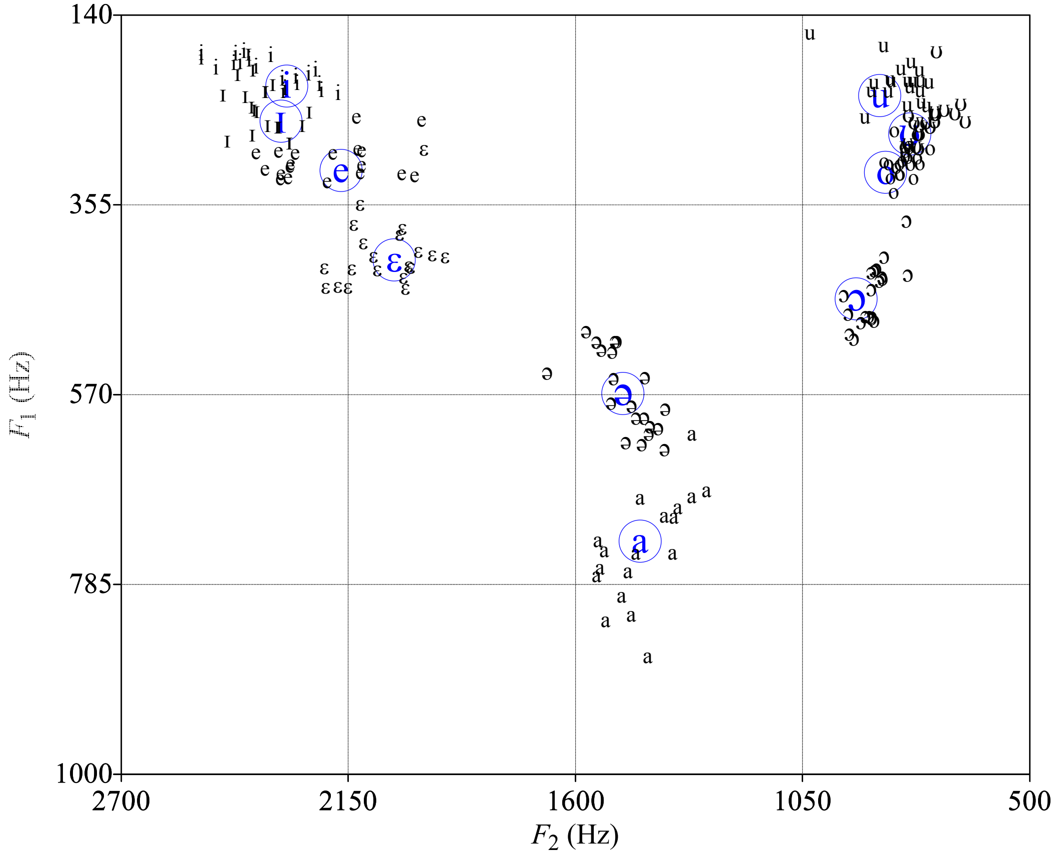


Figure 4.7: F1 vs. F2 vowel formant chart for Ikposo speaker 3, male (3M-K)

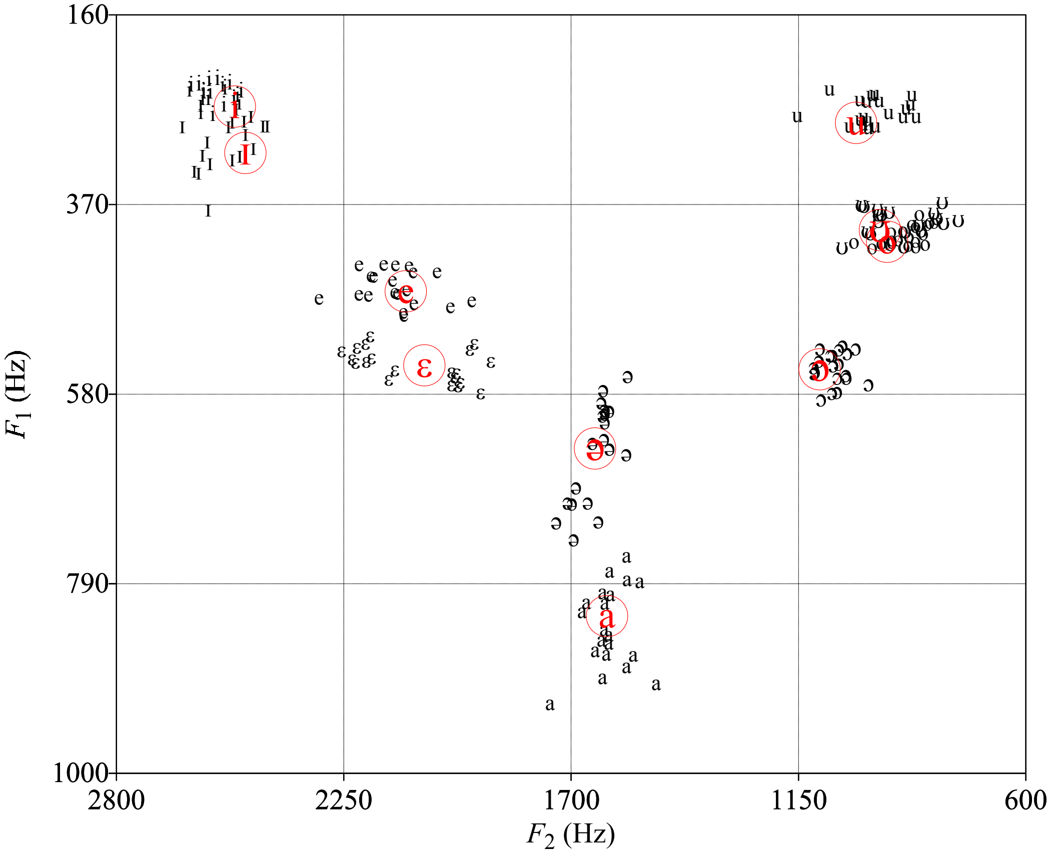


Figure 4.8: F1 vs. F2 vowel formant chart for Ikposo speaker 4, female (4F-E)

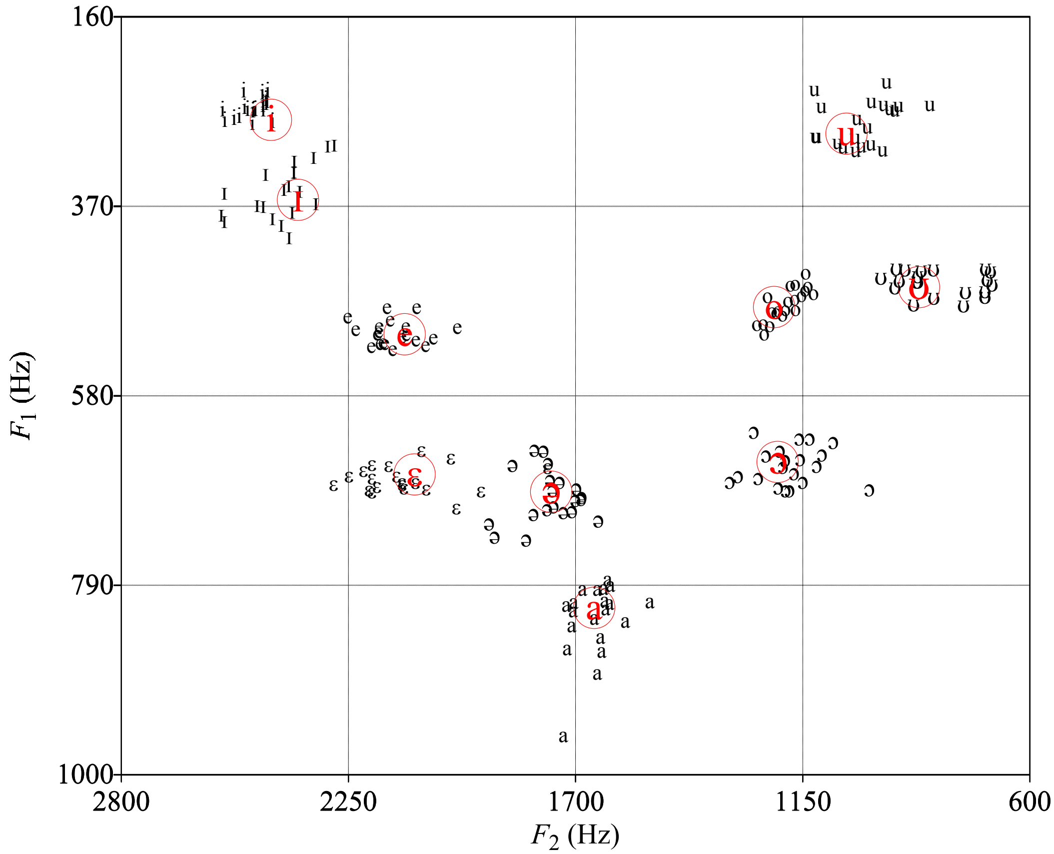


Figure 4.9: F1 vs. F2 vowel formant chart for Ikposo speaker 5, female (5F-R)

First, the F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, /e ɛ/, /ə ɑ/, /o ɔ/ and /u ʊ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). Because [ATR] interacts significantly with both Gender and Vowel Group [$F(4,975)=14.58$, $p=0.000$] but does not interact significantly with Gender alone [$F(1,975)=.405$], five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors. The level of significance is set at 0.01 for the analyses for each of the five speakers (i.e., the standard p value of 0.05 divided by 5). [ATR] interacts significantly with Vowel Group for all five speakers [1M-J *F*(4,189)= 151.31; 2M-Jo F(4,189)= 68.74; 3M-K F(4,187)= 32.22; 4F-E *F*(4,190)= 40.88; 5F-R *F*(4,190)= 24.51], with *p*=0.000; [+ATR] vowels have significantly lower F1 values than their [-ATR] counterparts.

In order to investigate cross-height pairs [ɪ e] and [ʊ o], the F1 values of all the vowels were submitted to one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.5, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.5: Ikposo F1 Mean Values by Vowel Group for Each Speaker

Superscript numbers indicate cross-height vowel means which are not significantly different. Yellow highlight indicates reversed order for cross-height vowels

Vowel Group	Vowel Quality	Pooled Data	1M-J	2M-Jo	3M-K	4F-E	5F-R
i	i [+ATR]	246	225	242	221	265	275
	ɪ [-ATR]	311	312	310	261	311	363
e	e [+ATR]	398	344	349	317	466	512
	ɛ [-ATR]	523	507	476	417	548	668
ɑ	ə [+ATR]	602	510	601	569	640	687
	ɑ [-ATR]	776	783	717	736	826	815
o	o [+ATR]	379[1]	338	346[1]	318	411[1]	482[1]
	ɔ [-ATR]	551	569	519	462	553	654
u	u [+ATR]	275	286	287	232	280	290
	ʊ [-ATR]	372[1]	389	340[1]	275	398[1]	460[1]

The main effect of Vowel Quality is significant for all speakers pooled, as well as for each Ikposo speaker [Pooled $F(9,985)=727.26$; 1M-J $F(9,189) = 1321.9$; 2M-Jo $F(9,189) = 1401.9$; 3M-K $F(9,187) = 525.4$; 4F-E $F(9,190) = 887.8$; 5F-R $F(9,190) = 1332.8$]. In every case, $p=0.000$. As anticipated, the model confirms that the mean differences for F1 between each [ATR] harmony pair are also statistically significant. F1 means for [+ATR] vowels are always significantly lower than their [-ATR] counterparts. The mean differences for cross-height vowel pairs [ɪ e] are also significant, with the [-ATR] high vowel having lower F1 means than the [+ATR] mid vowel for all speakers. The mean F1 values for [ʊ o], however, are not significantly different for three of the five speakers in the overall model: (2M-Jo, 4F-E, 5F-R). And while the results of these back vowels are significant for speaker 1M-J, the heights are reversed, with [o] occupying acoustic space higher than [ʊ].

The F1 data for the cross-height pairs [ɪ e] and [ʊ o], when submitted to separate ANOVA for all speakers and the individual speakers, mostly confirm the results of the overall model. As may be seen in Table 4.6, for all speakers, the two members of the front pair [ɪ e] present statistically significantly different F1 means. For the back pair [ʊ o], the statistically significant F1 mean differences of the pooled sample is reflected only in the results of speaker 2M-Jo.

Table 4.6: F1 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Ikposo

Shaded cells indicate mean values are not significantly different.
Where F1 means are significantly different, $p \leq 0.003$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	*F*(1,196)=93.99	*F*(1,198)=.582
1M-J	*F*(1,38)= 48.26	*F*(1,38)= 356.79
2M-Jo	*F*(1,37)= 24.48	*F*(1,38)= 3.52
3M-K	*F*(1,37)= 52.33	*F*(1,38)= 51.26
4F-E	*F*(1,38)= 433.08	*F*(1,38)=10.44
5F-R	*F*(1,38)= 449.38	*F*(1,38)= 21.03

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). As with the results for F1, [ATR] interacts significantly with both Gender and Vowel Group [*F*(4,975)=6.3 *p*=0.000] but does not interact significantly with Gender alone [*F*(1,975)=3.03]. Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors, the significance level set to 0.01 for each of the five speakers. [ATR] interacts significantly with Vowel Group for all five speakers [1M-J *F*(4,189)= 34; 2M-Jo *F*(4,189)= 80.13; 3M-K *F*(4,187)= 11.77; 4F-E *F*(4,190)= 19.33; 5F-R *F*(4,190)= 9.02]. In all cases, *p*=0.000. The main effect of [ATR] is not significant for two of the speakers [4F-E *F*(4,190)= .115 and 1M-J *F*(1,189)=.775]. These findings suggest that F2 does not consistently distinguish the [ATR] harmony pairs.

The F2 values for each speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.7.

Table 4.7: Ikposo F2 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-J	2M-Jo	3M-K	4F-E	5F-R
i	i [+ATR]	2293	2329	1992	2299	2504	2437
	ɪ [-ATR]	2300	2231	1984[1]	2313	2488	2372
e	e [+ATR]	2082	2057	1980[1]	2167	2100	2114
	ɛ [-ATR]	1994	1980	1807	2039	2055	2090
ɑ	ə [+ATR]	1538	1422	1378	1484	1642	1759
	ɑ [-ATR]	1488	1427	1299	1443	1613	1655
o	o [+ATR]	960	920	877	849[1]	935[1]	1220
	ɔ [-ATR]	1145	1020	974	921	1098	1211
u	u [+ATR]	911	860	786	855	1010	1044
	ʊ [-ATR]	842	765	833	791[1]	953[1]	869

As with F1, the main effect of Vowel Quality in Ikposo is also statistically significant [1M-J $F(9,189) = 2896.7$; 2M-Jo $F(9,189) = 3705.5$; 3M-K $F(9,187) = 1674.1$; 4F-E $F(9,190) = 1825.8$; 5F-R $F(9,190) = 1298.2$]. In every case, $p=0.000$. But as seen in Table 4.7, F2 does not reliably distinguish [ATR] pairs. This is most noticeable in high front vowels and low vowels where F2 mean values fail to distinguish [i] and [ɪ] in four of the five speakers and fail to distinguish [ə] and [ɑ] in three of the five speakers. Within speakers, F2 fails to distinguish three or more [ATR] harmony pairs for three of the speakers. In addition, F2 mean differences also fail to distinguish some of the cross-height vowels [ɪ]/[e] or [ʊ]/[o]. This is especially pertinent for speaker 4F-E, whose heights 2 and 3 back vowels were also not distinguished by F1 mean values in the ANOVA for all vowel groups.

One-way ANOVA, run on the vowel pairs individually, substantiate the above results for the front cross-height pair [ɪ]/[e] of speaker 2M-Jo and the back cross-height pair [ʊ]/[o] for speaker 4F-E. The differences in the F2 mean values for the back cross-height pair [ʊ]/[o] of speaker 3M-K, however, prove to be statistically significant.

Table 4.8: F2 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Ikposo

Shaded cells indicate mean differences are not significant.
Where F1 means are significantly different, $p = 0.000$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,196)=115.62$	$F(1,198)=52.31$
1M-J	$F(1,38)= 254.17$	$F(1,38)=453.4$
2M-Jo	$F(1,37)= .061$	$F(1,38)= 20.05$
3M-K	$F(1,38)= 52.33$	$F(1,38)= 29.73$
4F-E	$F(1,38)= 329.07$	$F(1,38)= .776$
5F-R	$F(1,38)= 147.33$	$F(1,38)= 270.73$

4.2.3 Kinande

The F1 vs. F2 formant plots for the four Kinande speakers of this study are found in Figures 4.10-4.13. As a reminder, Kinande has seven underlying vowels: /i ɪ ɛ ɑ ɔ ʊ u/. [+ATR] variants of [-ATR] mid and low vowels are produced in the environment of a [+ATR] high vowel (see § 2.2.1.3.2 for further detail), giving rise to three additional surface mid vowels, all [+ATR]: [e o ə].

For all four of the Kinande speakers, there is no apparent overlap in F1 for any of the underlying vowels. In addition, there is no overlap in F1 between height 3 and 4 vowels, that is between the [-ATR] mid vowels and their [+ATR] variants. The same is nearly so for the [-ATR] low and its [+ATR] variant, with only slightly overlapping F1 values for all of the speakers. Cross-height vowels [ɪ]/[e] and [ʊ]/[o] present a different picture and one similar to what we have already seen in Foodo and to a lesser degree in Ikposo. Namely, there is the tendency for these vowels to overlap for F1, as seen in the plots of 1M-Kk, 3M-J, and 4F-Jc, or for the [+ATR] height 3 vowels, [e] and [o], to have lower F1 values than [-ATR] height 2 vowels, [ɪ] and [ʊ] as may be seen in the plot for 2M-Ks. These tendencies for height 2 and 3 vowels have also been reported for another Kinande speaker in Gick et al. 2006.

In addition, the [+ATR] variant of the low vowel appears to overlap in F1 with [-ATR] mid vowels for several of the speakers: 2M-Ks, 3M-J 4F-Jc. This same tendency can also be noted in the scatterplot of the Kinande vowels found in Gick et al. 2006. Although the authors report that the differences between the mean F1 values of [ə] and [ɛ] are significant but that those between [ɑ] and [ɛ] are not, their accompanying scatterplot with 95% confidence ellipses suggests the reverse. This same tendency for [ə] and [ɛ] to overlap in F1 was also noted in two of the Ikposo speakers.

As for F2 differences between vowel pairs, all four speakers show some degree of overlap in F2 whether the [ATR] harmony pairs are both underlying or whether one of the pair is a surface realization only. This is especially noticeable in back vowels.

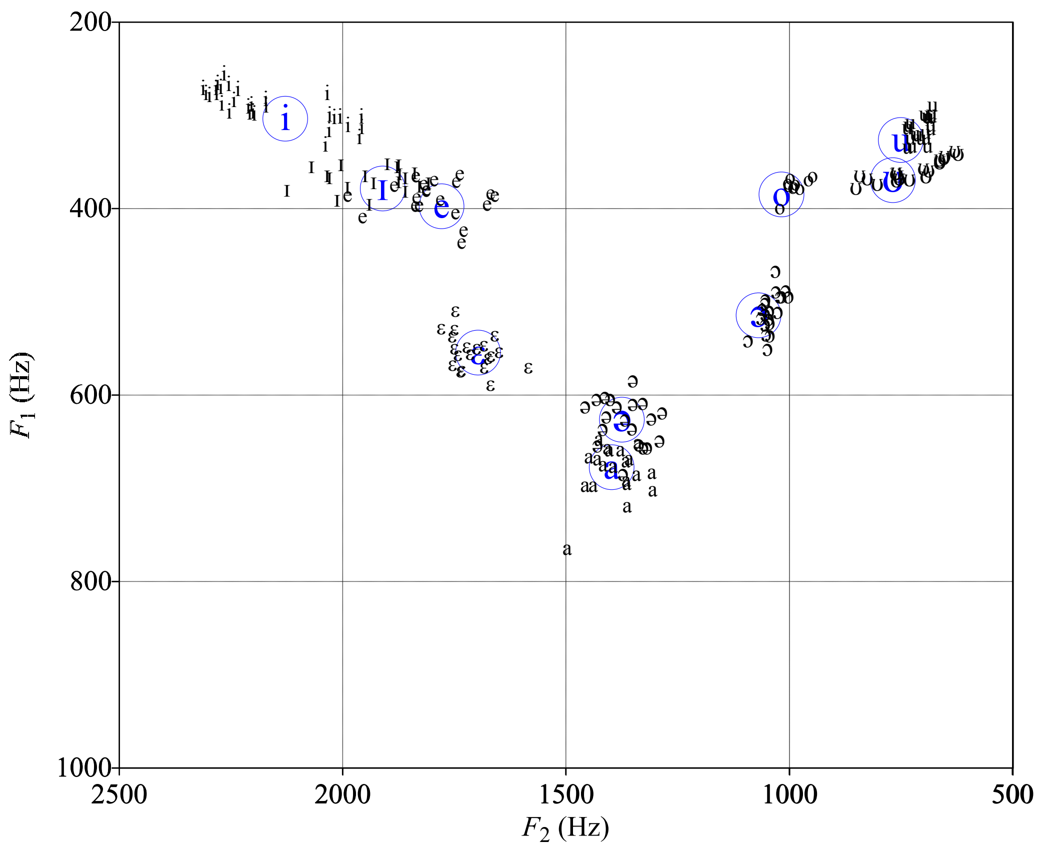


Figure 4.10: F1 vs. F2 vowel formant chart for Kinande speaker 1, male (1M-Kk)

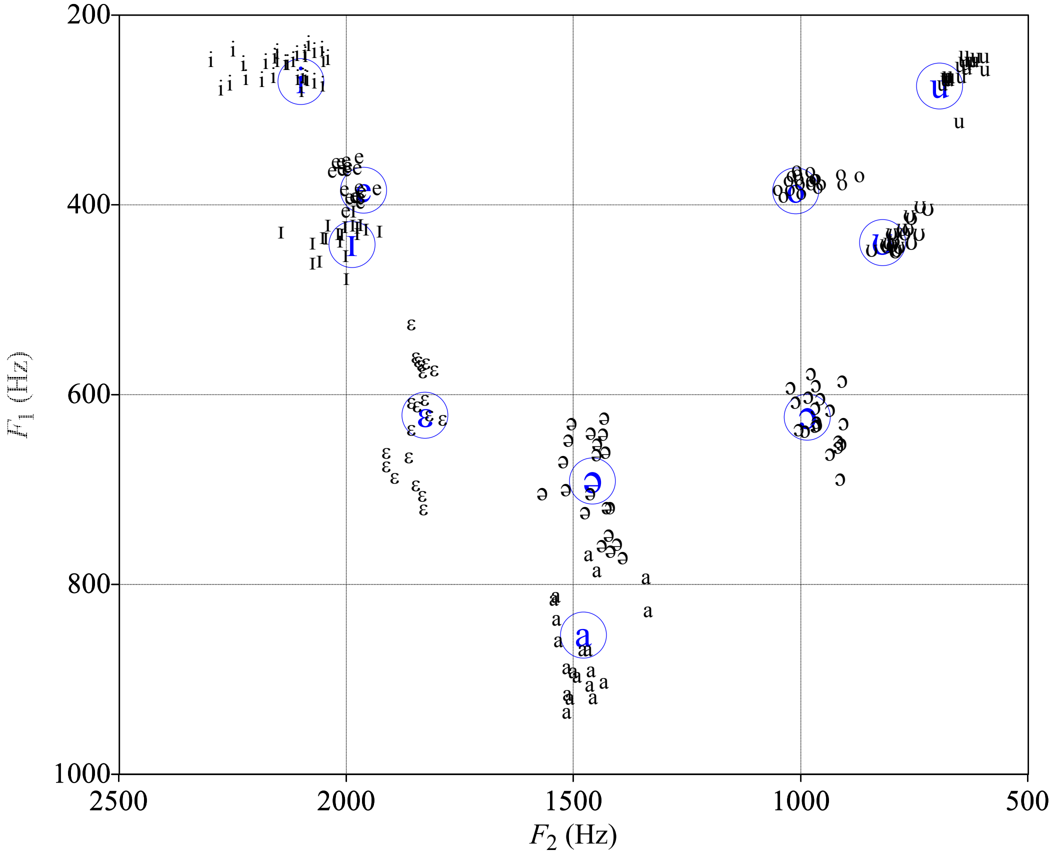


Figure 4.11: F1 vs. F2 vowel formant chart for Kinande speaker 2, male (2M-Ks)

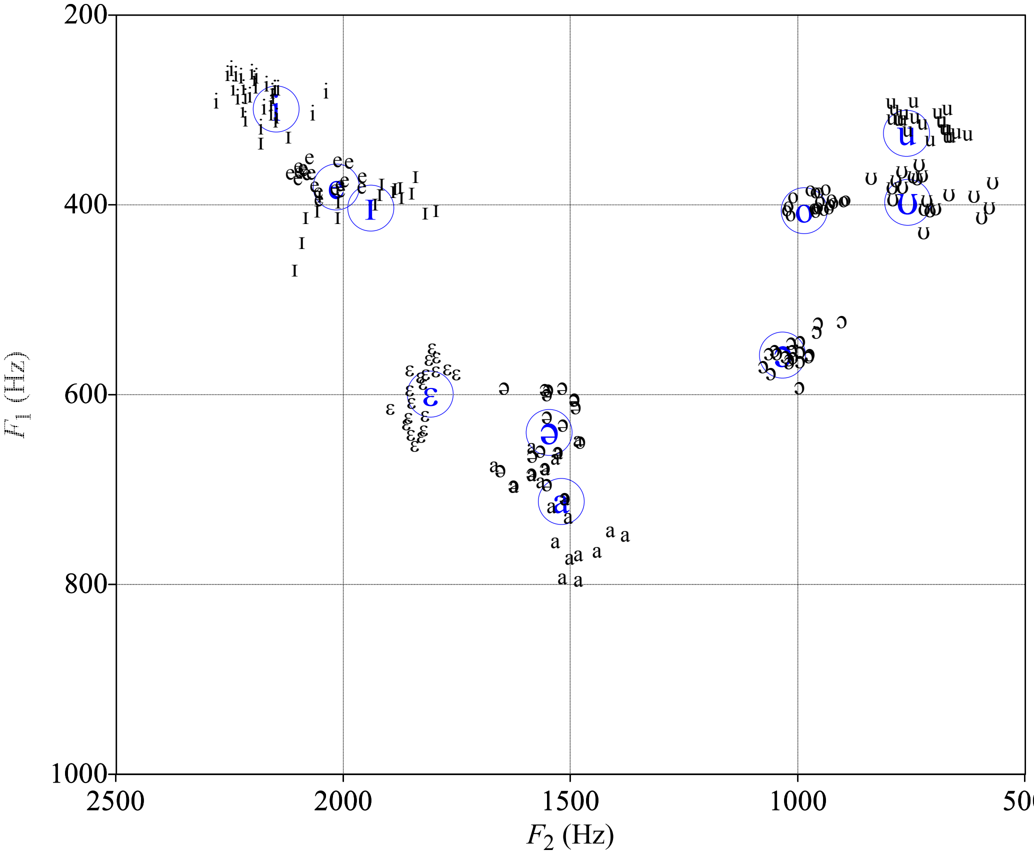


Figure 4.12: F1 vs. F2 vowel formant chart for Kinande speaker 3, male (3M-J)

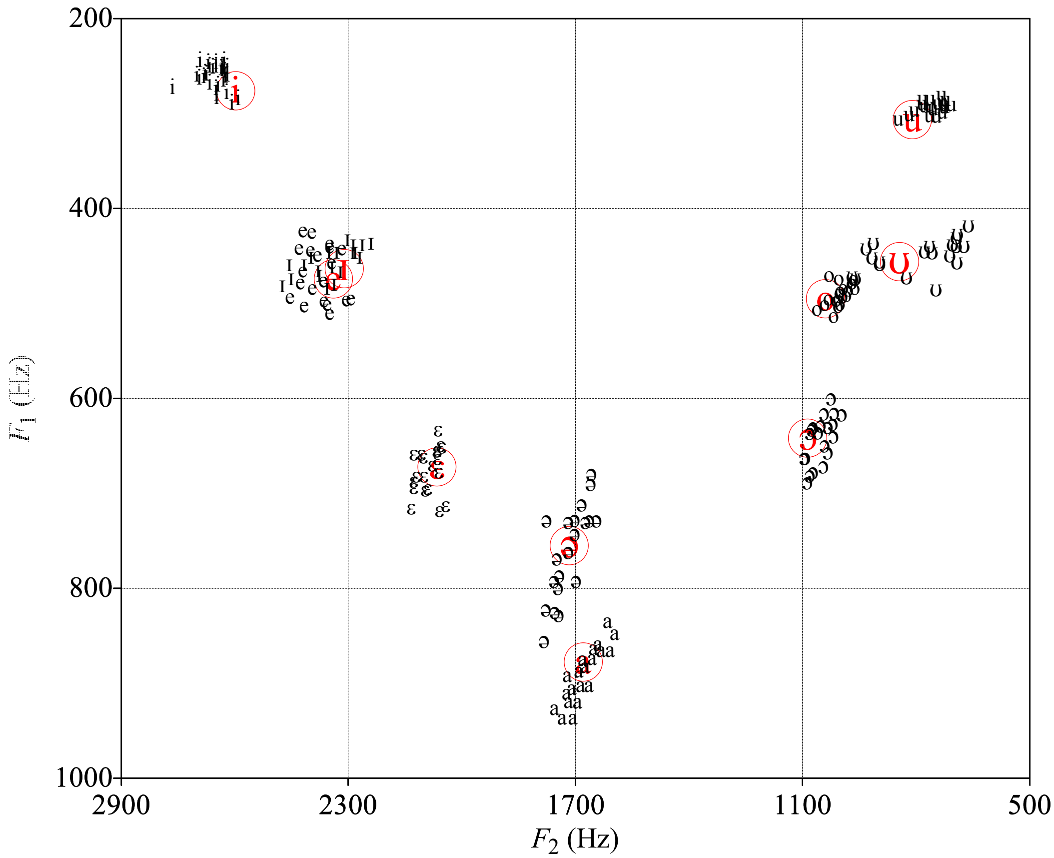


Figure 4.13: F1 vs. F2 vowel formant chart for Kinande speaker 4, female (4F-Jc)

The F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, [e ɛ], [ə ɑ], [o ɔ] and /u ʊ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with both Gender and Vowel Group [$F(4,810)=8.81$ $p=0.000$] as well as with Gender alone [$F(1,810)=15.91$ $p=0.000$]. Hence, four separate univariate ANOVA were run, one for each speaker with Vowel Group and [ATR] value as factors, with the level of significance set at 0.0125 for four speakers. [ATR] interacts significantly with Vowel Group for all four speakers [1M-Kk $F(4,190)=74.18$; 2M-Ks $F(4,200)=17.83$; 3M-J

F(4, 200)=62.04; 4F-Jc *F*(4, 200)=18.44], with *p*=0.000; [+ATR] vowels have significantly lower F1 values than their [-ATR] counterparts. The main effect of [ATR] is also significant for all four speakers [1M-Kk *F*(4,190)= 1213.35; 2M-Ks *F*(4,200)= 2172.69; 3M-J *F*(4, 200)= 1264.35; 4F-Jc *F*(4, 200)= 2460.11], with *p*=0.000, suggesting that while the F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, the effect is not consistent across vowel groups.

In order to investigate cross-height pairs [ɪ e] and [ʊ o], the F1 values of all the vowels were submitted to one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.0125 for four speakers). The mean F1 values are summarized in Table 4.9, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.9: Kinande F1 Mean Values by Vowel Group for Each Speaker

Superscript numbers indicate cross-height vowel mean differences which are not statistically significant.
Yellow highlight indicates reversed order for cross-height vowels

Vowel Group	Vowel Quality	Pooled Data	1M-Kk	2M-Ks	3M-J	4F-Jc
i	i [+ATR]	299	304	270	299	277
	ɪ [-ATR]	403^1	379	442	403^1	464^1
e	e [+ATR]	381^1	398	385	381^1	474^1
	ɛ [-ATR]	600	555	622	600	672
ɑ	ə [+ATR]	640	627	691	640	755
	ɑ [-ATR]	713	678	853	713	878
o	o [+ATR]	407^1	385^1	385	407^2	495
	ɔ [-ATR]	558	515	624	558	642
u	u [+ATR]	326	327	277	326	307
	ʊ [-ATR]	397^1	370^1	440	397^2	456

The main effect of Vowel Quality is significant for all speakers, pooled, as well as for each individual Kinande speaker [Pooled $F(9,820) = 880.57$; 1M-Kk $F(9,190) = 1121.2$; 2M-Ks $F(9,200) = 869$; 3M-K $F(9,200) = 704.1$; 4F-Jc $F(9,200) = 1492$]. In every case, p=0.000. As anticipated, the model confirms that the mean differences for F1 between the two vowels in each [ATR] harmony pair are also statistically significant. F1 means for [+ATR] vowels are always significantly lower than their [-ATR] counterparts. As further expected, several of the cross-height vowel pairs have F1 mean differences which are not significant. This is true for the front vowels [ɪ]/[e] for speakers 3M-J and 4F-Jc, and for back vowels [ʊ]/[o] for speakers 1M-Kk and 4F-Jc. As noted above, the height of these pairs of vowels is reversed for speaker 2M-Ks (highlighted in yellow in Table 4.9), with the [+ATR] mid vowels having significantly lower F1 means than the [-ATR] high vowels. Unlike the findings in Gick et al. 2006, the apparent overlap between cross-height vowels [ə] and [ɛ] is not significant for any of the speakers.

The cross-height pairs [ɪ e] and [ʊ o] were submitted to separate ANOVA for the pooled data as well as for each individual speaker. The results support those of the overall model only marginally. As seen in Table 4.10, as in the overall model, the F1 mean values of [ɪ e] and [ʊ o] are not significantly different for the pooled speaker data; they are also not significantly different for the [ɪ e] of the female speaker 4F-Jc. In all other cases, the differences prove to be statistically significant.

Table 4.10: F1 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Kinande

Shaded cells indicate mean differences are not significant.
Where F1 mean differences are significant, $p < 0.05$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,158)=3.83$	$F(1,148)=1.01$
1M-Kk	$F(1,38)= 15.25$	$F(1,28)= 14.5$
2M-Ks	$F(1,38)= 121.86$	$F(1,38)= 247.16$
3M-J	$F(1,38)= 9.91$	$F(1,38)= 4.62$
4F-Jc	$F(1,38)= 2.39$	$F(1,38)= 77.36$

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). As with the results for F1, [ATR] interacts significantly with both Gender and Vowel Group [$F(4,810)=6.5$ $p=0.000$] as well as with Gender alone [$F(1, 810)=23.81$ $p=0.000$]. Four separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.0125 for four speakers). [ATR] interacts significantly with Vowel Group for all four speakers [1M-Kk $F(4, 190)=27.66$; 2M-Ks $F(4, 200)=60.32$; 3M-J $F(4,200)=44.84$; 4F-Jc $F(4, 200)=123.71$]. In all cases, $p=0.000$. The main effect of [ATR] is also significant for all of the speakers [1M-Kk $F(4, 190)= 17.35$; 2M-Ks $F(4, 200)= 18.21$; 3M-J $F(4,200)= 98.05$; 4F-Jc $F(4, 200)= 236.96$], suggesting that F2 may distinguish [ATR] harmony pairs in some cases, but that the effect is not consistent across Gender and Vowel Group.

The F2 values for each speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.11, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.11: Kinande F2 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-Kk	2M-Ks	3M-J	4F-Jc
i	i [+ATR]	2147	2128	2100	2147	2598
	ɪ [-ATR]	1940	1910	1987[1]	1940	2310[1]
e	e [+ATR]	2016	1778	1962[1]	2016	2339[1]
	ɛ [-ATR]	1809	1697	1827	1809	2065
ɑ	ə [+ATR]	1547	1375	1459	1547	1716
	ɑ [-ATR]	1521	1397	1479	1521	1679
o	o [+ATR]	986	1017	1012	986	1040
	ɔ [-ATR]	1034	1069	986	1034	1087
u	u [+ATR]	763	750	696	763	810
	ʊ [-ATR]	757	768	821	758	844

As with F1, the main effect of Vowel Quality is significant for the pooled data as well as for each speaker [Pooled $F(9,820) = 1296.33$; 1M-Kk $F(9,190) = 1083.8$; 2M-Ks $F(9,200) = 3148.6$; 3M-K $F(9,200) = 1820.8$; 4F-Jc $F(9,200) = 4237.8$]. In each case, p=0.000. F2, however, proves to be a weak indicator of [ATR] differences among back vowels. Only two of the speakers, 2M-Ks and 4F-Jc, have one vowel pair with significantly different F2 means. F2 means are also not significantly different for cross-height vowel pairs [ɪ]/[e] for speakers 2M-Ks and 4F-Jc. Consequently, [ɪ] and [e] are distinguished neither by F1 nor by F2 in the model of speaker 4F-Jc's speech.

One-way ANOVA run on the vowel pairs individually substantiate the above results for the front cross-height pair [ɪ]/[e] of female speaker 4FM-Jc. Both pairs for the rest of the speakers have significantly different F2 mean values. The results of both the overall ANOVA model as well as individual ANOVA indicate that there is no statistical difference for the F1 and F2 mean values for the front cross-height pair [ɪ]/[e] of female speaker 4FM-Jc.

Table 4.12: F2 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Kinande

Shaded cells indicate mean differences are not significant.
Where F1 means are significant, $p < 0.05$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,158)=.175$	$F(1,148)=429.81$
1M-Kk	$F(1,38)= 25.20$	$F(1,28)=129.24$
2M-Ks	$F(1,38)= 4.7$	$F(1,38)= 274.24$
3F-J	$F(1,38)= 8.27$	$F(1,38)= 167.78$
4F-Jc	$F(1,38)= 2.85$	$F(1,38)= 70.25$

4.2.4 LuBwisi

The F1 vs. F2 formant plots for the five LuBwisi speakers of this study are found in Figures 4.14-4.18. Like Kinande, LuBwisi also has an underlying seven vowel system: /i ɪ ɛ ɑ ɔ ʊ u/, with [+ATR] variants of [-ATR] vowels produced in the environment of a [+ATR] high vowel (see § 2.2.1.3.1 for further detail). The same three additional surface vowels appear: [e o ə].

LuBwisi parallels the Kinande vowel space in several ways: There is little to no overlap of F1 values for the underlying vowels, while cross-height vowels [ɪ]/[e] and [ʊ]/[o] exhibit considerable overlap either in F1 or F2 and sometimes for both (2M-H, 3M-W, 5F-Z). There is likewise an apparent overlap of the [+ATR] variant of the low vowel with [-ATR] mid vowels, [ɛ] or [ɔ] for some speakers (2M-H, 4F-T).

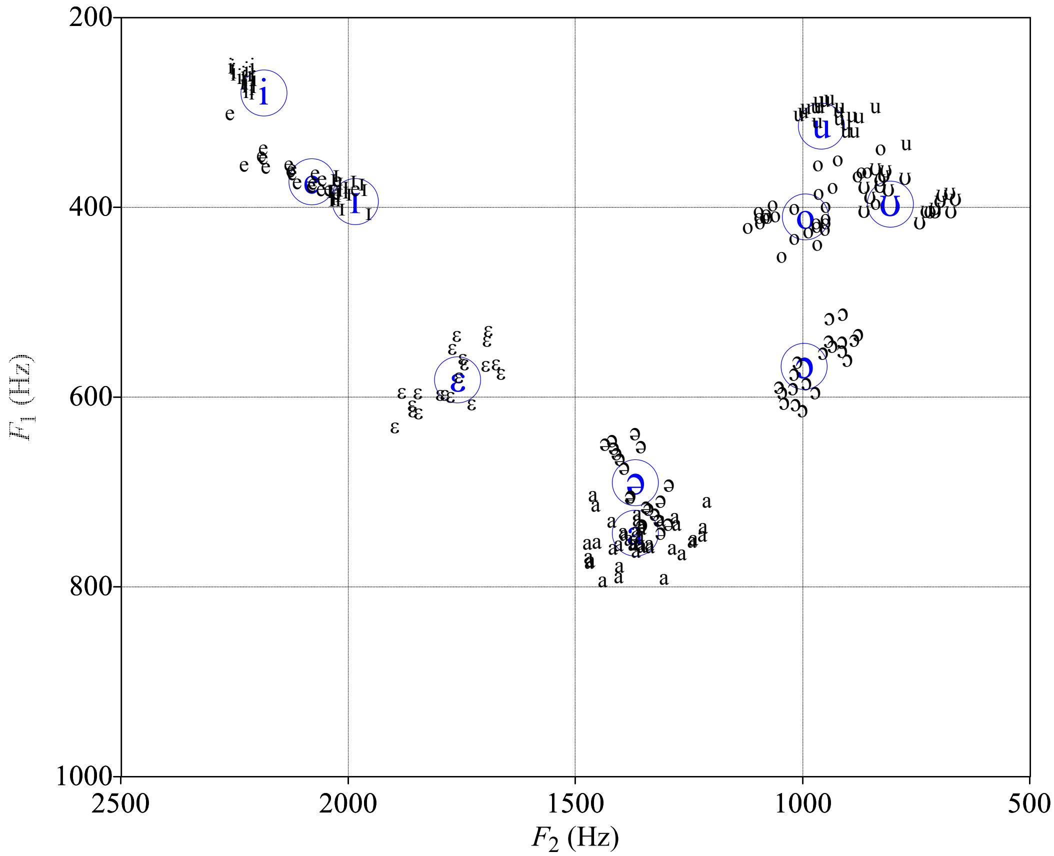


Figure 4.14: F1 vs. F2 vowel formant chart for LuBwisi speaker 1, male (1M-B)

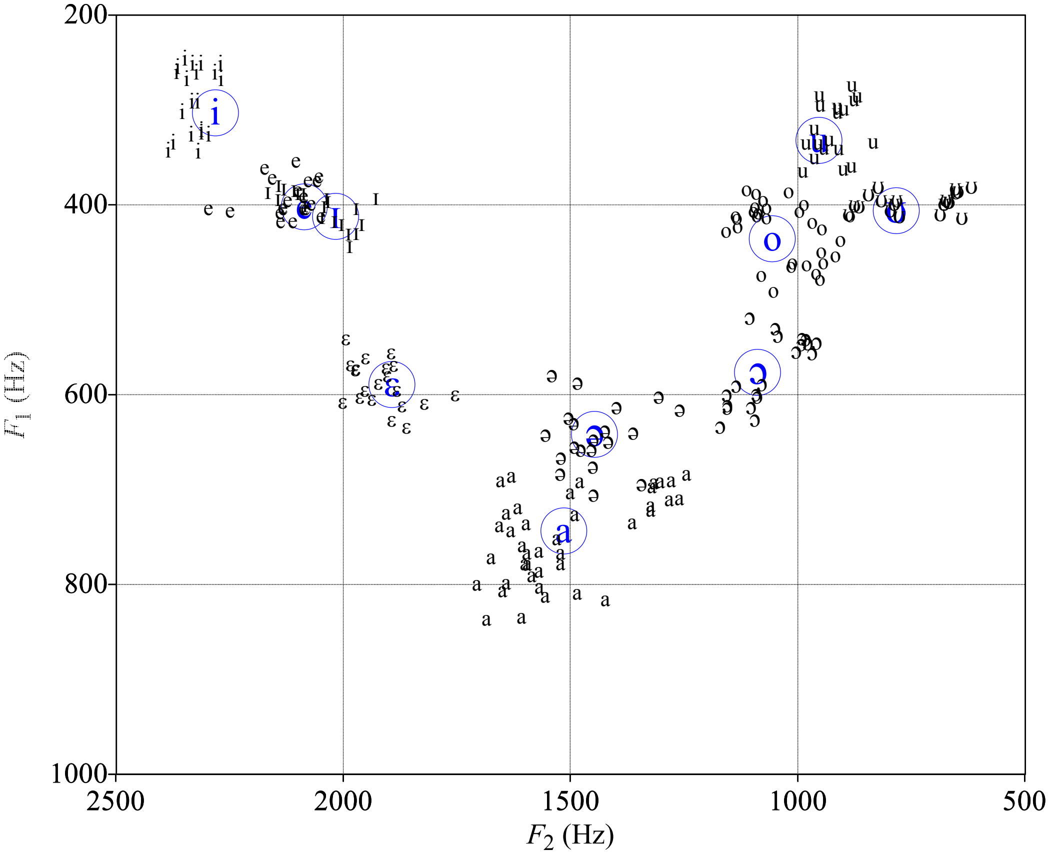


Figure 4.15: F1 vs. F2 vowel formant chart for LuBwisi speaker 2, male (2M-H)

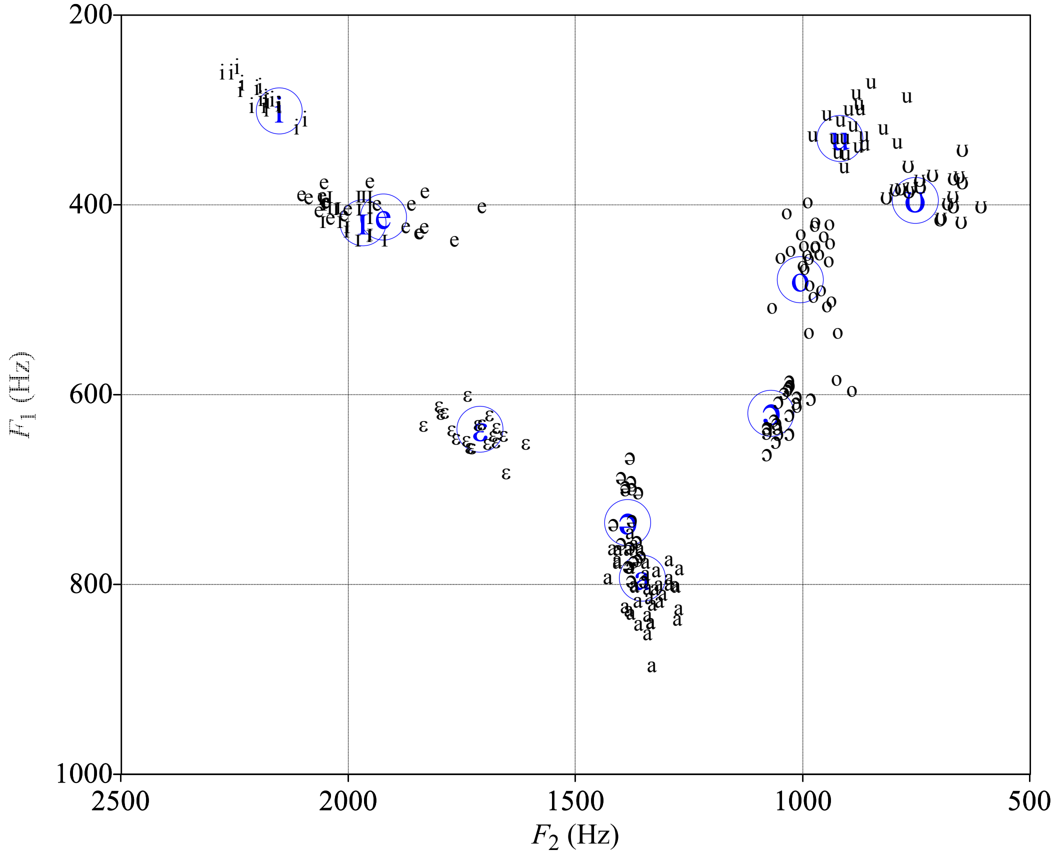


Figure 4.16: F1 vs. F2 vowel formant chart for LuBwisi speaker 3, male (3M-W)

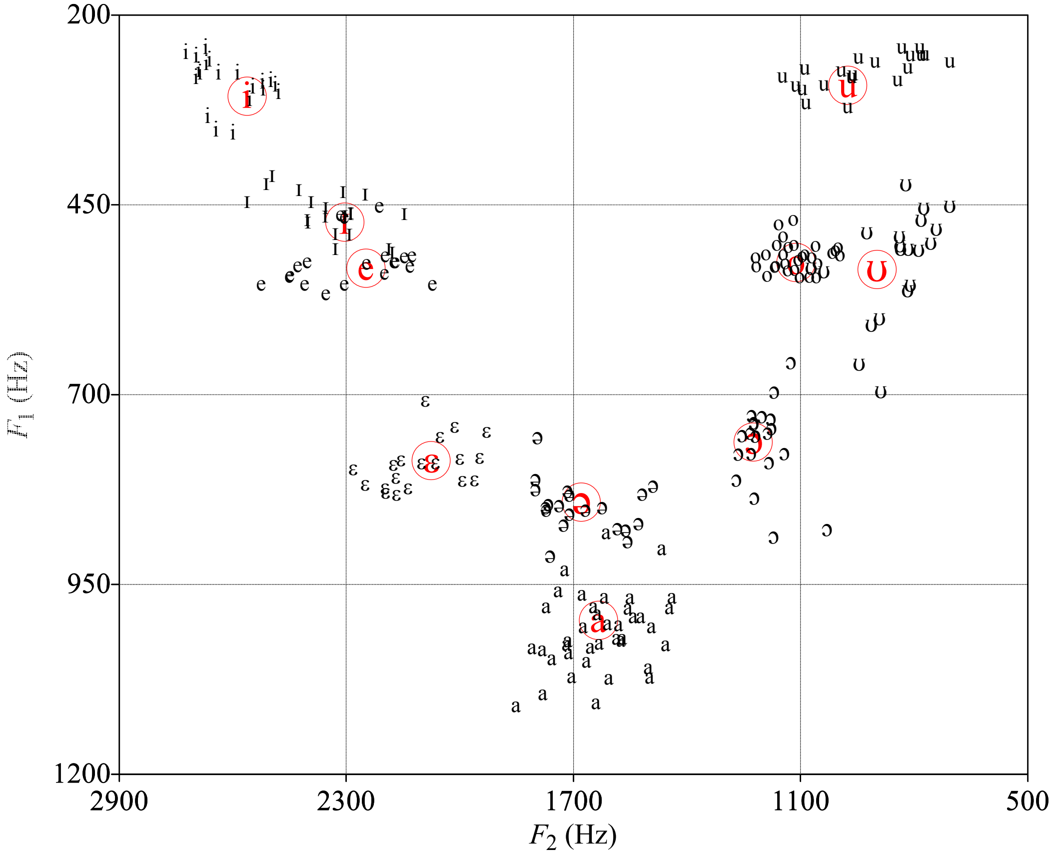


Figure 4.17: F1 vs. F2 vowel formant chart for LuBwisi speaker 4, female (4F-T)

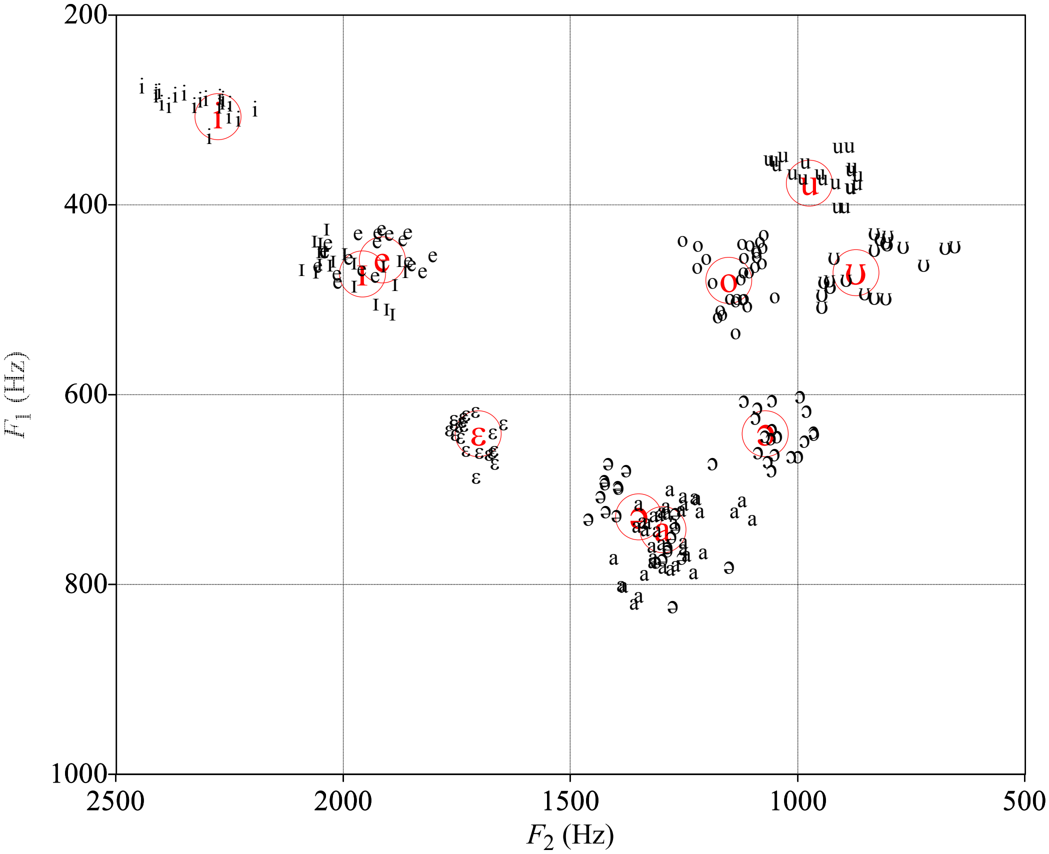


Figure 4.18: F1 vs. F2 vowel formant chart for LuBwisi speaker 5, female (5F-Z)

First, the F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, [e ɛ], [ə ɑ], [o ɔ] and /u ʊ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with both Gender and Vowel Group [$F(4,1128)=1167.64$ $p=0.000$] as well as with Gender alone [$F(1, 1128)=44.27$ $p=0.000$]. The main effect of [ATR] is also significant [$F(1,1128)=1885.11$ $p=0.000$]. Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to

0.01 for five speakers). [ATR] interacts significantly with Vowel Group for all five speakers [1M-B $F(4, 220)=88.22$; 2M-H $F(4, 220)=20.7$; 3M-W $F(4, 220)=57$; 4F-T $F(4, 218)=15.82$; 5F-Z $F(4, 220)=94.47$] In all cases, $p=0.000$; The main effect of [ATR] is also significant for all five speakers [1M-B $F(4, 220)=1723.24$; 2M-H $F(4, 220)= 889.47$; 3M-W $F(4, 220)= 949.39$; 4F-T $F(4, 218)= 1587.62$; 5F-Z $F(4, 220)= 1321.44$], with $p=0.000$. [+ATR] vowels have significantly lower F1 values than their [-ATR] counterparts suggesting that while the F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, the effect is not consistent across vowel groups and gender.

In order to investigate cross-height pairs [ɪ e] and [ʊ o], the F1 values of all the vowels were submitted to one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.13, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.13: LuBwisi F1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-B	2M-H	3M-W	4F-T	5F-Z
i	i [+ATR]	300	280	304	301	307	308
	ɪ [-ATR]	434[1]	394[1]	413[1]	419[1]	473	473[1]
e	e [+ATR]	436[1]	373[1]	403[1]	413[1]	533	458[1]
	ɛ [-ATR]	646	582	589	637	787	642
ɑ	ə [+ATR]	728	690	642	735	842	729
	ɑ [-ATR]	803	744	744	794	998	743
o	o [+ATR]	466[2]	410[2]	436	479	526[1]	479[1]
	ɔ [-ATR]	634	568	577	620	535	641
u	u [+ATR]	330	315	333	331	293	377
	ʊ [-ATR]	441[2]	397[2]	407	396	535[1]	472[1]

The main effect of Vowel Quality is significant for all speakers as well as for each LuBwisi speaker [Pooled $F(9,1138) = 788.04$; 1M-B $F(9,220) = 1379$; 2M-H $F(9,220) = 606.8$; 3M-W $F(9,220) = 897$; 4F-T $F(9,218) = 917.4$; $F(9,220) = 842.8$]. In every case, p=0.000. As anticipated, the model confirms that the mean differences for F1 between each [ATR] harmony pair are statistically significant. With one notable exception, F1 means for [+ATR] vowels are always significantly lower than their [-ATR] counterparts, whether both members of a set are underlying forms or one is a surface variant. For one of the female speakers, 5F-Z, F1 differences between the low vowel and its [+ATR] counterpart are not significant. As expected, many of the cross-height vowel pairs [ɪ]/[e] and [ʊ]/[o] present F1 mean values that are not significantly different. For four of five speakers, F1 differences do not distinguish [ɪ] and [e], while for three, [ʊ] and [o] are not distinguished by F1. Unlike Kinande, there is no tendency among these speakers for a reversal of vowel height, i.e. for [-ATR] high vowels to have higher F1 means than [+ATR] mid vowels. As in Kinande, the apparent overlap of cross–height [ə] and [ɛ] or [ɔ] is also superficial. Differences in mean F1 values are significant between these vowels.

In further investigation, cross–height pairs [ɪ e] and [ʊ o] were submitted to separate ANOVA for all speakers and for each individual speaker. The results largely support those of the overall ANOVA model. As seen in Table 4.14, the F1 mean values of [ɪ e] are significantly different for the combined speaker data but not for [ʊ o]; they are also not significantly different for the [ɪ e] of speakers 1M–B and 5F–Z. In all other cases, the differences follow the same pattern found in the overall ANOVA.

In addition, a one–way ANOVA was conducted on the F1 values of [ATR] vowel pair [ə]/[ɑ] for speaker 5F–Z. The results indicate that the mean F1 values are not significantly different [$F(1,58) = 2.23$].

Table 4.14: F1 Mean Differences for Cross–Height Pairs [ɪ]–[e] and [ʊ]–[o] in LuBwisi

Shaded cells indicate mean differences are not significant.
Where F1 means are significantly different, $p \leq 0.001$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	*F*(1,198)=.057	*F*(1,248)=11.51
1M-B	*F*(1,38)= 20.25	*F*(1,48)= 3.91
2M-H	*F*(1,38)= 3.29	*F*(1,48)= 18.5
3M-W	*F*(1,38)= 1.39	*F*(1,48)= 46.9
4F-T	*F*(1,38)= 44.34	*F*(1,48)= .503
5F-Z	*F*(1,38)= 5.54	*F*(1,48)= 1.06

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). [ATR] interacts significantly with both Gender and Vowel Group [*F*(4,1128)=3.49 *p*=0.008] but not with Gender alone [*F*(1, 1128)=.177]. Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for all five speakers [1M-B *F*(4, 220)= 40.01; 2M-H *F*(4, 220)= 37.98; 3M-W *F*(4, 220)= 58.98; 4F-T *F*(4, 218)= 16.03; 5F-Z *F*(4, 220)= 31.28]. In all cases, *p*=0.000. The main effect of [ATR] is also significant for all of the speakers [1M-B *F*(4, 220)= 184.31; 2M-H *F*(4, 220)= 94.07; 3M-W *F*(4, 220)= 231.92; 4F-T *F*(4, 218)= 31.69; 5F-Z *F*(4, 220)= 305.16]. This suggests that F2 may in some cases distinguish [ATR] harmony pairs, but that the effect is not consistent across Gender and Vowel Group.

The F2 values for each speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.15, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.15: LuBwisi F2 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-B	2M-H	3M-W	4F-T	5F-Z
i	i [+ATR]	2291	2186	2282	2151	2561	2275
	ɪ [-ATR]	2046[1]	1984	2017[1]	1968[1]	2304[1]	1958[1]
e	e [+ATR]	2050[1]	2080	2086[1]	1923[1]	2248[1]	1914[1]
	ɛ [-ATR]	1826	1759	1893	1710	2076	1704
ɑ	ə [+ATR]	1446	1368	1448	1385	1680	1350
	ɑ [-ATR]	1432	1369	1514	1354	1633	1296
o	o [+ATR]	1064	995	1057	1006	1111	1151
	ɔ [-ATR]	1090	997	1089	1070	1224	1072
u	u [+ATR]	956	959	953	918	975	974
	ʊ [-ATR]	823	807	784	753	897	873

As with F1, the main effect of Vowel Quality is significant for each speaker [Pooled $F(9,1138) = 1599.32$; 1M-B $F(9,220) = 1038.7$; 2M-H $F(9,220) = 913.1$; 3M-W $F(9,220) = 1894.7$; 4F-T $F(9,218) = 571.3$; $F(9,220) = 1128.7$]. In all cases, p=0.000. F2 mean differences fail to distinguish [ATR] harmony pairs consistently. In particular, F2 mean differences are not significant for the low vowel and its [+ATR] variant across speakers. F2 also fails to distinguish front cross-height vowels [ɪ] and [e] for four of the five speakers. Thus for speakers 2M-H, 3MW and 5F-Z, neither F1 nor F2 means are significantly different for these vowels.

One-way ANOVA, run on the vowel pairs individually, largely substantiate the above results. Three of the four speakers whose front cross-height pair [ɪ]/[e] did not have significant F2 mean differences in the overall ANOVA also do not present significant differences in the individual ANOVA. For speaker 2M-H, the individual ANOVA indicates that their mean values are significantly different.

Table 4.16: F2 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in LuBwisi

Shaded cells indicate mean differences are not significant.
Where F1 means are significantly different, $p \leq 0.001$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,198)=.038$	$F(1,248)=266.18$
1M-B	$F(1,38)= 33.78$	$F(1,48)= 31.53$
2M-H	$F(1,38)= 12.25$	$F(1,48)= 144.07$
3M-W	$F(1,38)= 2.77$	$F(1,48)= 376.18$
4F-T	$F(1,38)= 2.38$	$F(1,48)= 22.28$
5F-Z	$F(1,38)= 3.72$	$F(1,48)= 233.84$

4.2.5 Ekiti

The F1 vs. F2 formant plots for the three Ekiti-Yoruba and one Mọba-Yoruba speakers of this study are found in Figures 4.19-4.22. Like Kinande and LuBwisi all the variants of Yoruba have underlying seven vowel systems. Unlike Kinande and LuBwisi, Ekiti has /i e ɛ ɑ ɔ o u/ as its vowel inventory, with [-ATR] variants of [+ATR] high vowels produced when preceding a [-ATR] vowel (see § 2.2.2.1 for further detail). This gives rise to two additional surface vowels: [ɪ ʊ]. Mọba, the variant spoken by speaker 4F-N, is reported to not have the additional surface vowels.

For the three Ekiti speakers, the following may be noted from their formant charts: no apparent overlap of F1 values for any of the underlying seven vowels, with the exception of marginal overlap of back vowels [ɑ] and [ɔ] for speaker 2M-M. There is, however, some overlap of height 2 and 3 vowels especially as noticeable in the back vowels [ʊ]/[o] for all three speakers and in front vowels [ɪ]/[e] for speaker 2M-M. In addition, the height 3 front vowel [e] sits higher in acoustic space than the height 2 front vowel [ɪ] in the speech of 3F-F. Some vowel pairs also appear to overlap for F2, notably [i]/[ɪ] for speaker 1M-A, [u]/[ʊ] and [o]/[ɔ] for speaker 2M-M and 3F-F.

In spite of the fact that Przezdziecki used tokens with word-medial labial or velar consonants and I used tokens with primarily medial alveolar consonants, these results for Ekiti are not unlike those found in Przezdziecki 2005 for the Akurẹ speakers in his study of Yoruba dialects. For example, examing the results of the F1 vs. F2 vowel charts of Akurẹ (Przezdziecki 2005:165ff), reveals that for some speakers [+ATR] [e] sits higher in acoustic space than [-ATR] [ɪ]. One noticeable difference between the formant results of our respective studies, however, is that there tends to be a wider spread of F2 values for the [+ATR] high back vowel for speakers 1M-A and 2M-M. The more centralized F2 values are from those tokens with /t/ as the medial consonant. This effect was so pronounced in speaker 3F-F that a different word with a voiceless post-alveolar [ʃ] was substituted. Otherwise, the trajectories of the vowel means for both studies are very similar.

The presence of data from a Mọba speaker (4F-N) along with the Ekiti speakers was explained earlier in §2.2.2.1; the results of the analysis of this speaker's vowels are included here for comparison's sake both with the Ekiti speakers of this study as well as with the Mọba speakers of the Przezdziecki 2005 study. As this speaker had the same set of words recorded for her as for the rest of the speakers, the vowel tokens have been coded in the same manner: initial [i] occurring before a [-ATR] vowel in V2 position has been transcribed as [ɪ]. Likewise, initial [u] before a [-ATR] vowel in V2 position has been transcribed as [ʊ]. The results are again not unlike those described for Mọba in Przezdziecki 2005. As expected, there is no apparent overlap for F1 values between those vowels transcribed as underlying vowels /i e ɛ ɑ ɔ o u/. As anticipated from Przezdziecki, there is considerable overlap between [u] and transcribed [ʊ], suggesting that these vowels are not separate surface forms (or in Przezdziecki's terms, little to no vowel to vowel coarticulation effect) with the more centralized F2 values for the tokens of both of these vowels due to an alveolar plosive preceding or following the target vowel. The front high vowels, though, do not show the same overlap as the back vowels but pattern more like to the front high vowels of speaker 1M-A, with transcribed [ɪ] sitting acoustically between [i] and [e].

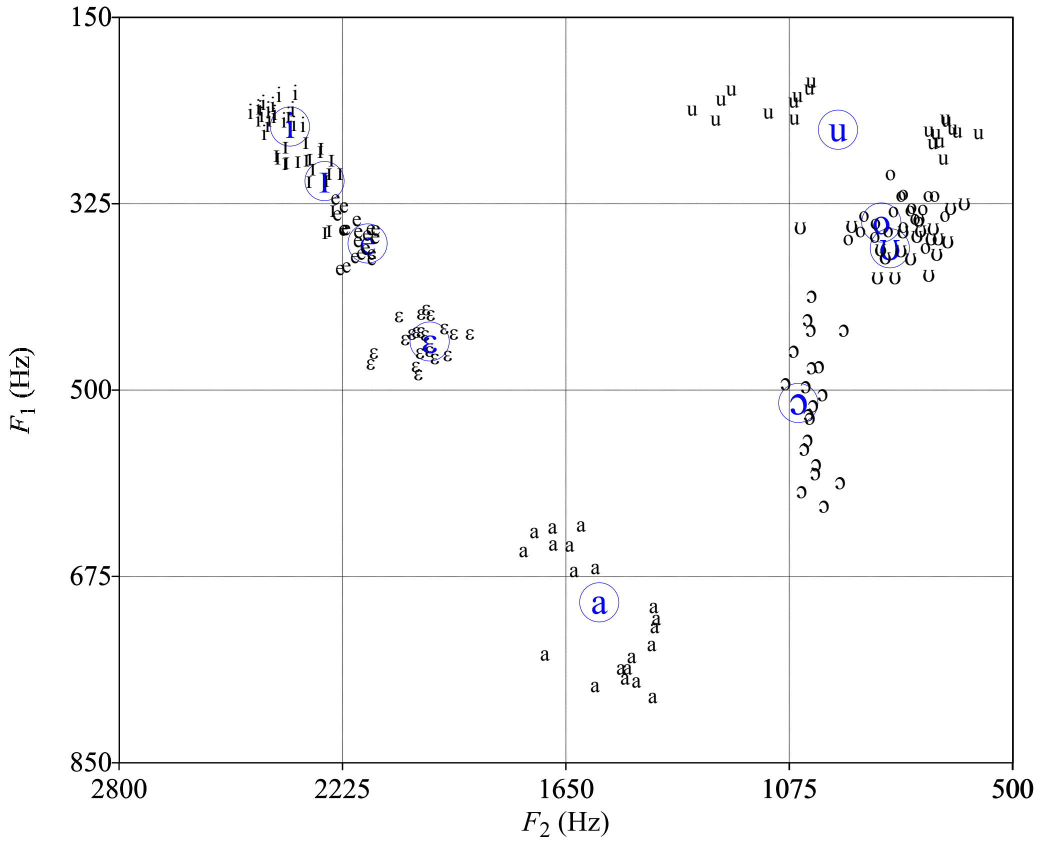


Figure 4.19: F1 vs. F2 vowel formant chart for Ekiti speaker 1, male (1M-A)

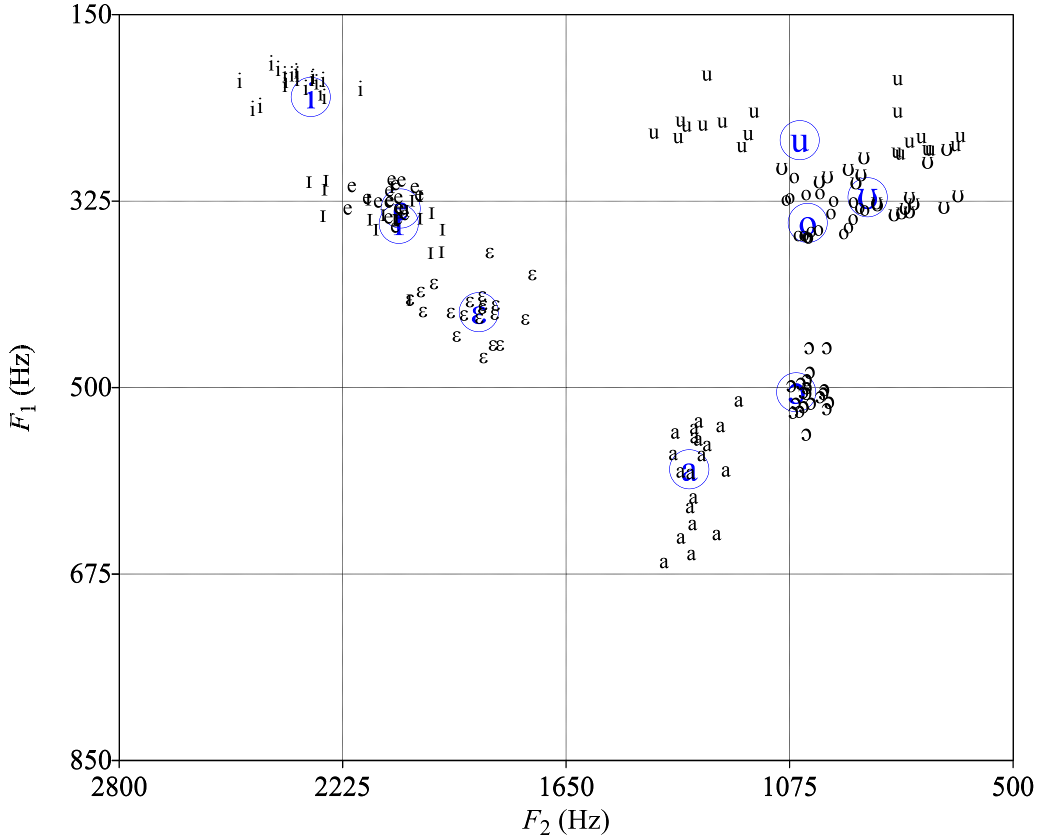


Figure 4.20: F1 vs. F2 vowel formant chart for Ekiti speaker 2, male (2M-M)

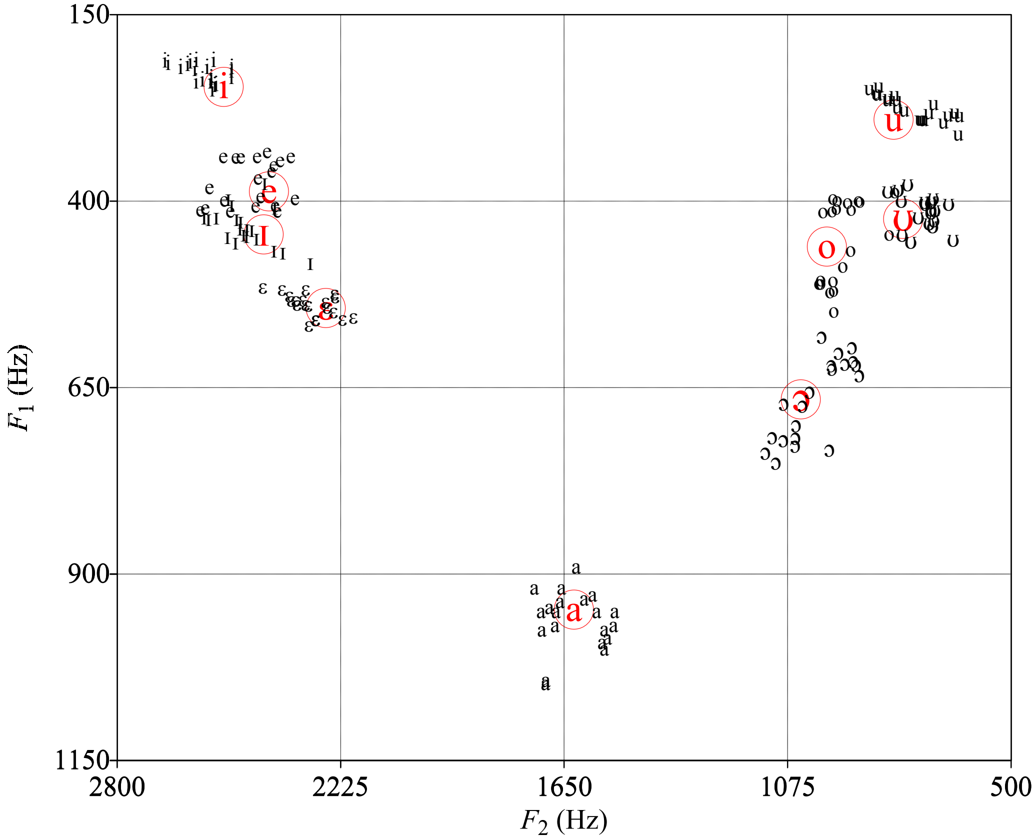


Figure 4.21: F1 vs. F2 vowel formant chart for Ekiti speaker 3, female (3F-F)

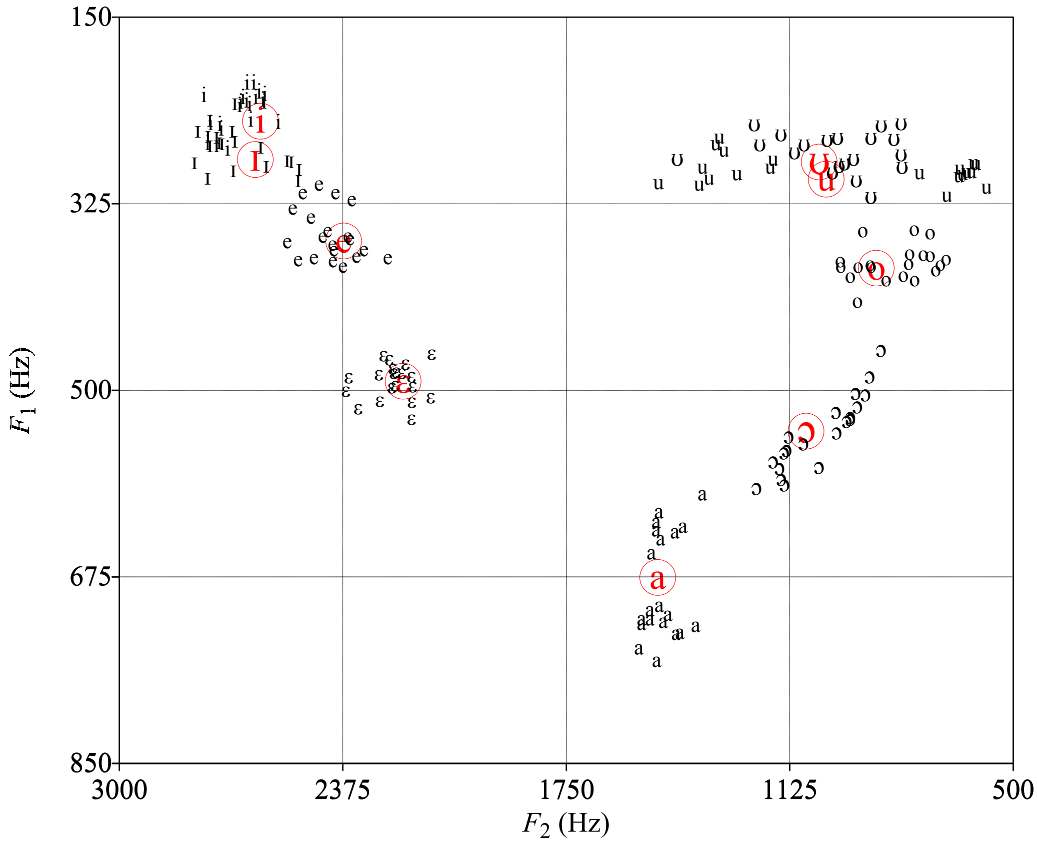


Figure 4.22: F1 vs. F2 vowel formant chart for Ekiti (Mọba) speaker 4, female (4F-N)

First, the F1 values of the [ATR] harmony pairs, for the three Ekiti speakers, were submitted to a univariate ANOVA with three factors: Vowel Group ([i ɪ], /e ɛ/, /o ɔ/ and [u ʊ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with both Gender and Vowel Group [$F(3,463)=8.69$ $p=0.000$] as well as with Gender alone [$F(1, 463)=146.81$ $p=0.000$]. Three separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.0167 for three speakers). [ATR] interacts significantly with Vowel Group for all three Ekiti speakers [1M-A $F(3,152)=37.22$; 2M-M $F(3,151)=55.98$; 3F-F $F(3,152)=11.55$]. In all cases, $p=0.000$; [+ATR] vowels have significantly lower F1 values than their [-ATR] counterparts. The main effect of [ATR] is also significant for all four speakers with [+ATR] vowels having significantly lower F1 means than their [-ATR] counterparts [1M-A $F(3,152)=37.22$; 2M-M $F(3,151)=55.98$; 3F-F $F(3,152)=11.55$]. In all cases, $p=0.000$. These results suggest that while the F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, the effect is not consistent across vowel groups or gender.

A separate univariate ANOVA was run for the Mọba speaker, 4F-N, with Vowel Group and [ATR] value as factors. This yielded similar results as the ANOVA for the Ekiti speakers. [ATR] interacts significantly with Vowel Group [$F(3,152)=157.58$, $p=0.000$]. The main effect of [ATR] is also significant [$F(1,152)=573.19$, $p=0.000$].

In order to investigate cross-height pairs [ɪ e] and [ʊ o], the F1 values of all the vowels for the Ekiti speakers and for the Mọba speaker were submitted to one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all the Ekiti speakers as well as for each speaker (significance level set to 0.0167 in Ekiti for three speakers). The mean F1 values are summarized in Table 4.17, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The Mọba speaker is set off from the Ekiti speakers by a double vertical bar.

Table 4.17: Ekiti F1 Means by vowel pair for each speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different. Highlighted cells indicate reversed height order

Vowel Group	Vowel Quality	Pooled (Ekiti)	1M-A	2M-M	3F-F	4F-N (Mọba)
i	i [+ATR]	242	253	227	247	248
	ɪ [-ATR]	365[1]	304	346[1]	445	284
e	e [+ATR]	360[1]	362	332[1]	387	360
	ɛ [-ATR]	475	454	429	543	491
ɑ	ɑ [-ATR]	741	699	577	948	675
o	o [+ATR]	383[1]	342[1]	345[1]	461	385
	ɔ [-ATR]	561	512	504	666	538
u	u [+ATR]	271	255	268	291	302
	ʊ [-ATR]	371[1]	367[1]	321[1]	424	286

The main effect of Vowel Quality is significant for all Ekiti speakers, each Ekiti speaker, and for the Mọba speaker [Pooled $F(8,530)=262.91$; 1M-A $F(8,171) = 445.46$; 2M-M $F(8,170) = 486.44$; 3F-F $F(8,171) = 851.79$; 4F-N $F(8,171) = 154.77$]. In all cases, $p=0.000$. For the Ekiti speakers, the mean differences between each [ATR] harmony pair are also significant, whether both members of a set are underlying forms or one member is a surface form only. As may be seen in Table 4.17, mean F1 values for [+ATR] vowels are always significantly lower than their [-ATR] counterparts. Several of the cross-height vowel pairs fail to have significantly different means: the back vowels [ʊ]/[o] for speakers 1M-A and 2M-M and the front vowels [ɪ]/[e] for 2M-M have F1 mean differences that are not significant. Additionally, the [-ATR] high vowel [ɪ] has F1 means some 50 Hz higher than the [+ATR] mid vowel [e] for speaker 3F-F.

As for the vowels of Mọba speaker 4F-N, as anticipated, the differences in mean F1 of high back vowels [u] and [ʊ] are not significant, but those of the front high vowels [i] and [ɪ] are. These results parallel those of Przezdziecki (2005) where he presents data for four Mọba speakers which suggest that the F1 values of [i] in V1 position are subject to coarticulation effects. For three of the speakers of his study, F1 means for [i] before [-ATR] V2s are significantly higher than F1 means before [+ATR] V2s. This is true, but to a lesser degree, for [u] in V1 position.[46]

One-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor for cross-height pairs [ɪ e] and [ʊ o] are summarized in Table 4.18. Height 2 and 3 vowels prove to be distinguished by significantly different F1 means for all speakers. In this case, the results of individual Ekiti speakers are more reliable than their combined data. This is due to the difference in the direction of the height 2 and 3 vowels of 1M-A. That is, the F1 mean values for his height 2 vowels are lower than those of his height 3 vowels.

[46] As I was asking different research questions at the time of recording than Przezdziecki, I do not have instances of [i] in V1 position before a [+ATR] V2 to test this for the one Moba speaker in my study.

Table 4.18: F1 F1 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Ekiti and Mọba

Shaded cells indicate mean differences are not significant.
Where F1 means are significantly different, $p < 0.05$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Ekiti	*F*(1,158)=.235	*F*(1,148)=1.25
1M-A	*F*(1,38)= 83.38	*F*(1,28)= 18.96
2M-M	*F*(1,38)= 5.34	*F*(1,37)= 18.27
3M-F	*F*(1,38)= 44.55	*F*(1,38)= 8.7
4F-N Mọba	*F*(1,38)= 136.43	*F*(1,38)= 359.64

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). As with the results for F1, [ATR] interacts significantly with both Gender and Vowel Group [*F*(3,463)=3.13 *p*=0.025] as well as with Gender alone [*F*(1 463)=4.53 *p*=0.034]. Three separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.0167 for three speakers). [ATR] interacts significantly with Vowel Group for all three Ekiti speakers [1M-A *F*(3,152)= 29.73; 2M-M *F*(3,151)= 9.75; 3F-F *F*(3,152)= 24.24]. In all cases, *p*=0.000. The main effect of [ATR] is also significant for all of the speakers [1M-A *F*(3,152)= 690.44; 2M-M *F*(3,151)= 1338.73; 3F-F *F*(3,152)= 1180.49]. This suggests that F2 may in some cases distinguish [ATR] harmony pairs, but that the effect is not consistent across Gender and Vowel Group.

A separate univariate ANOVA was run for the F2 values of the Mọba speaker, 4F-N, with Vowel Group and [ATR] value as factors. This yielded similar results as the ANOVA for the Ekiti speakers. [ATR] interacts significantly with Vowel Group

[F(3,152)=10.1, p=0.000]. The main effect of [ATR], however, is not significant [F(1,152)=.459]. These results suggest that F2 does not reliably distinguish [ATR] harmony pairs for this Mọba speaker.

The F2 values for each speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.19, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.19: Ekiti F2 Mean Values by Vowel Pair for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled (Ekiti)	1M-A	2M-M	3F-F	4F-N (Mọba)
i	i [+ATR]	2398	2360	2307	2526	2605
	ɪ [-ATR]	2249[1]	2256[1]	1983[1]	2450[1]	2619
e	e [+ATR]	2220[1]	2175[1]	2076[1]	2410[1]	2372
	ɛ [-ATR]	2046	2001	1875	2263	2206
ɑ	ɑ [-ATR]	1507	1564	1334	1625	1494
o	o [+ATR]	947	837[2]	1029	974	883
	ɔ [-ATR]	1050	1051	1058	1041	1079
u	u [+ATR]	934	949	1049	801	1023
	ʊ [-ATR]	822	816[2]	875	778	1042

As with F1, the main effect of Vowel Quality is significant for all Ekiti speakers, each Ekiti speaker and for the Mọba speaker [Pooled Ekiti F(8,530)=1167.64; 1M-A F(8,171) = 804.15; 2M-M F(8,170) = 423.87; 3F-F F(8,171) = 3098.43; 4F-N F(8,171) = 555.43]. In all cases, p=0.000. F2 mean differences do not distinguish [ATR] harmony pairs in all cases for the Ekiti speakers. Each speaker has one vowel group that cannot be distinguished by F2 mean differences. For the Mọba speaker, neither the vowels of the "i" group nor the vowels of the "u" group are distinguished by F2 mean differences. Not surprisingly, [u] and transcribed [ʊ] are not distinguished by either F1 or F2 mean differences.

As several of the cross-height vowel pairs have F2 means which are not statistically significantly different in the overall ANOVA, individual one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor were also conducted. The results are summarized in Table 4.20. Again, the Mọba speaker is set off from the Ekiti speakers by a double vertical bar. The results largely confirm the overall ANOVA model. The front cross-height pair for speaker 1M-A have significantly different F2 means according to the individual ANOVA. All other results mirror those of the overall ANOVA.

Table 4.20: F2 Mean Differences for Cross-Height Pairs [ɪ]-[e] and [ʊ]-[o] in Ekiti and Mọba

Shaded cells indicate mean differences are not significant.
Where F1 means are significantly different, $p \leq 0.005$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Ekiti	$F(1,118)=.854$	$F(1,117)=49.44$
1M-A	$F(1,38)= 23.24$	$F(1,38)= .742$
2M-M	$F(1,38)= .474$	$F(1,37)= 28.71$
3M-F	$F(1,38)= .413$	$F(1,38)= 182.04$
4F-N Mọba	$F(1,38)= 95.39$	$F(1,38)= 15.66$

4.2.6 Ifè

The F1 vs. F2 formant plots for the five Ifè speakers of this study are found in Figures 4.23-4.27. Like other Yoruba-related languages, Ifè has the underlying seven vowel system: /i e ɛ ɑ ɔ o u/. Unlike Ekiti or Mọba, Ifè [ATR] mid-vowel harmony is restricted to word roots. Thus, there are no surface variants. There is, however, evidence that Ifè has coalescent [-ATR] harmony (see §2.2.2.2 for further detail).

Especially noticeable in these charts is wide range of F1 values for some speakers' mid vowels. This is especially so for speaker 5F-M whose [-ATR] mid back vowel spans nearly a 200 Hz range. The lower end of this range and the upper end of the [+ATR] back mid vowel come close to overlapping. Some speakers also exhibit a degree of marginal F1 overlap for [+ATR] [u] and [o] vowels. This is true for speaker 2M-Y and 3M-K in particular.

Ifè presents a very different picture for F2 than what we have seen so far. There appears to be little to no overlap of F2 values for [e] and [ɛ] or for [o] and [ɔ]. In addition, although the target vowels used in the study have only voiceless alveolar consonants in their syllable onsets, there is little to no centralization of high back vowels. Across speakers, Ifè use of acoustic vowel space presents a V-shaped trajectory.

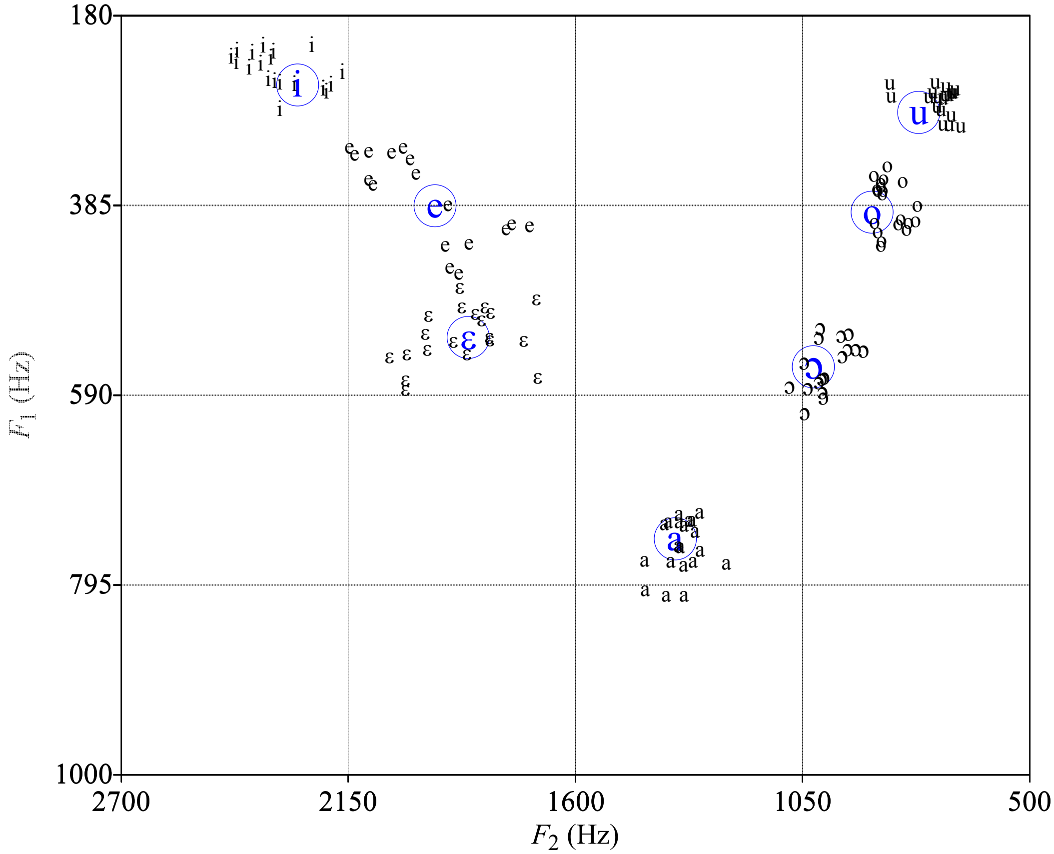


Figure 4.23: F1 vs. F2 vowel formant chart for Ifè speaker 1, male (1M-Kv)

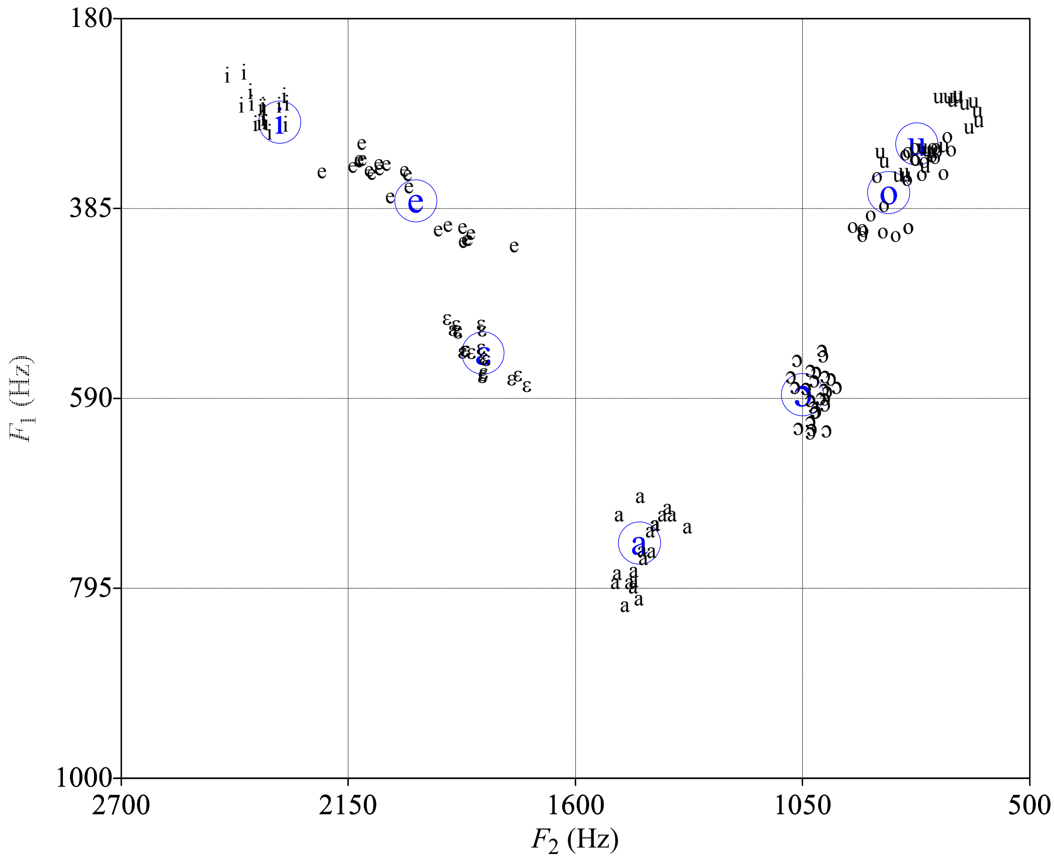


Figure 4.24: F1 vs. F2 vowel formant chart for Ifè speaker 2, male (2M-Y)

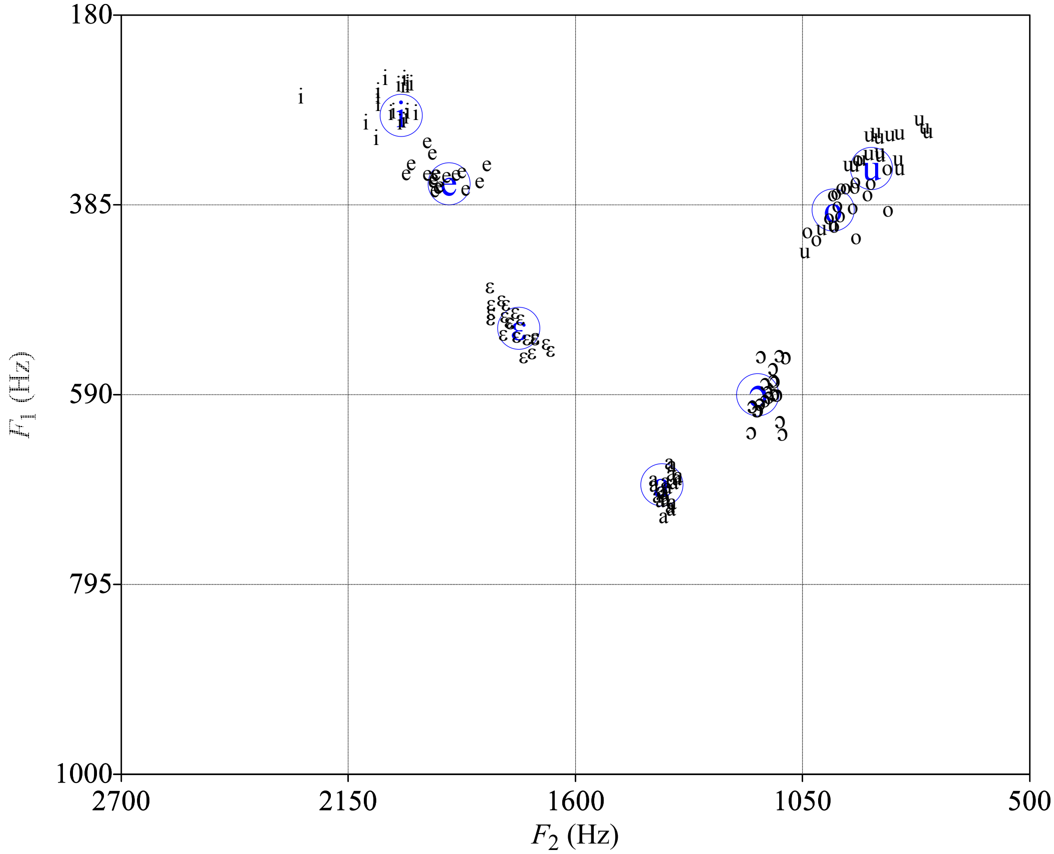


Figure 4.25: F1 vs. F2 vowel formant chart for Ifè speaker 3, male (3M-K)

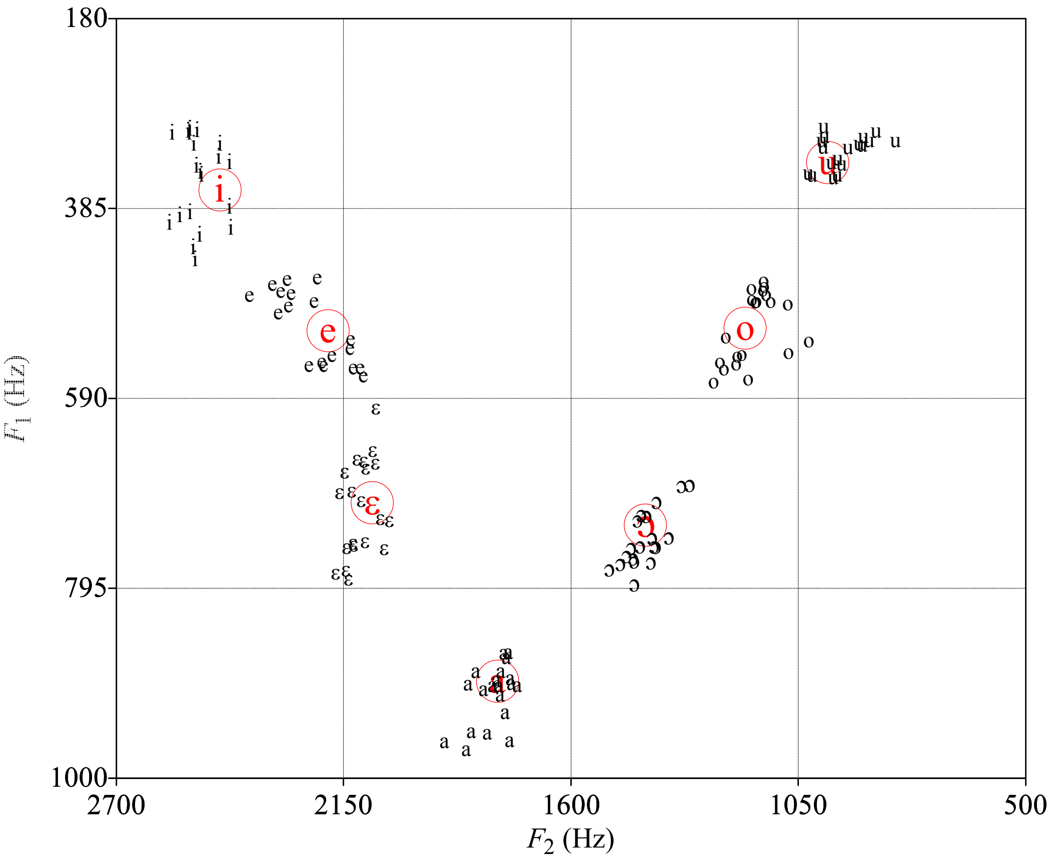


Figure 4.26: F1 vs. F2 vowel formant chart for Ifè speaker 4, female (4F-I)

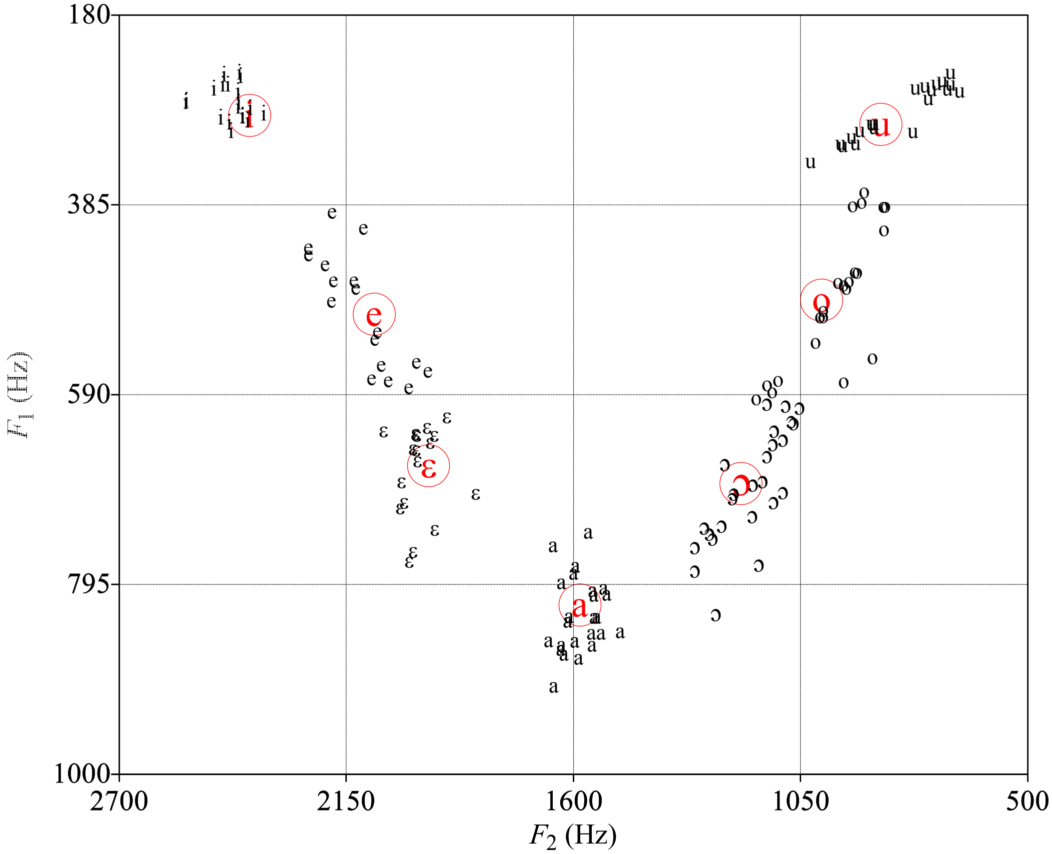


Figure 4.27: F1 vs. F2 vowel formant chart for Ifè speaker 5, female (5F-M)

The F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] does not interact significantly with either Gender or Vowel Group [$F(1,398)=.529$]. The main effect of [ATR], however, is significant [$F(1,398)=1962.63$ $p=0.000$], indicating that there are differences in F1 means within the vowel pairs and that they are consistent across gender.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for two of the five speakers [2M-Y $F(1, 93)=18.93$ $p=0.000$ and 3M-K $F(1,73)=21.21$ $p=0.000$] but not for the rest [1M-Kv $F(1,74)= 2.73$ p=0.103; 4F-I $F(1,72)=3.98$ p=0.05; 5F-M $F(1,78)=1.68$ p=0.199]. The main effect of [ATR] is also significant for all five speakers [1M-Kv $F(1,74)=426.77$; 2M-Y $F(1,93)=942.41$; 3M-K $F(1,73)=1439.71$; 4F-I $F(1,72)= 522.91$; 5F-M $F(1,78)= 180.18$]. In all cases, $p=0.000$. [+ATR] vowels have significantly lower F1 means than their [-ATR] counterparts. These results suggest that while the F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, the effect is not consistent across vowel groups for every speaker.

To further investigate the Ifè vowel system, the F1 values of all the vowels of each Ifè speaker were submitted to a one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.21, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.21: Ifè F1 Mean Values by Vowel Group for Each Speaker

Vowel Group	Vowel Quality	Pooled Data	1M-Kv	2M-Y	3M-K	4F-I	5F-M
i	i [+ATR]	300	256	292	289	366	289
e	e [+ATR]	426	386	377	363	517	503
	ɛ [-ATR]	590	528	541	519	703	667
ɑ	ɑ [-ATR]	780	746	746	688	895	818
o	o [+ATR]	429	393	368	391	517	488
	ɔ [-ATR]	632	560	586	590	736	686
u	u [+ATR]	316	285	316	346	336	298

The main effect of Vowel Quality is significant for all speakers as well as for each Ifè speaker [Pooled $F(6,700)$=665.86; 1M-Kv $F(6,126) = 752.6$; 2M-Y $F(6,150) = 672.6$; 3M-K $F(6,130) = 803.6$; 4F-I $F(6,128) = 604.9$; 5F-M $F(6,138) = 345.8$]. In every case, p=0.000. F1 mean differences are significant for mid vowels pairs [e]/[ɛ] and [o]/[ɔ] as well as for cross-height vowel pairs [i]/[e] and [u]/[o].

Next, the F2 values of the [ATR] harmony pairs were submitted to the univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). As with the results for F1, [ATR] does not interact significantly with either Gender and Vowel Group [$F(1,398)$=.018] or with Gender alone [$F(1,398)$=1.74]. The main effect of [ATR], however, is significant [$F(1,398)$= 13 p=0.000], suggesting that there may be differences in F2 means within the vowel pairs and that they are consistent across gender. Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for all five Ifè speakers

[1M-Kv *F*(1,74)=31.38; 2M-Y *F*(1,93)=164.88; 3M-K *F*(1,73)=337.29; 4F-I *F*(1,72)=202.75; 5F-M *F*(1,78)=94.02]. In all cases, *p*=0.000. The main effect of [ATR], however, is significant for only one speaker [4F-I *F*(1,72)=32.19 p=0.000] but not for the rest [1M-Kv *F*(1,74)= 2.4; 2M-Y *F*(1,93)= 2.5; 3M-K *F*(1,73)= .656; 5F-M *F*(1,78)= 3.49]. These results suggest that any differences are not consistent across vowel pairs.

For a clearer picture of the Ifè vowel system, the F2 values of all speakers and for each Ifè speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.22, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

As with F1, the main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled *F*(6,700)=1491.15; 1M-Kv *F*(6,126) = 1183.8; 2M-Y *F*(6,150) = 1925.9; 3M-K *F*(6,130) = 817; 4F-I *F*(6,128) = 2158.5; 5F-M *F*(6,138) = 1267]. In every case, *p*=0.000. As predicted, all F2 mean values are significant for every speaker, as well as for all speakers.

Table 4.22: Ifè F2 Mean Values by Vowel Group for Each Speaker

Vowel Group	Vowel Quality	Pooled Data	1M-Kv	2M-Y	3M-K	4F-I	5F-M
i	i [+ATR]	2284	2272	2316	2022	2449	2383
e	e [+ATR]	2019	1940	1986	1908	2188	2083
	ɛ [-ATR]	1889	1859	1823	1738	2080	1950
ɑ	ɑ [-ATR]	1514	1358	1444	1391	1778	1584
o	o [+ATR]	967	881	841	976	1182	999
	ɔ [-ATR]	1166	1024	1050	1159	1429	1194
u	u [+ATR]	844	768	773	883	976	856

4.2.7 Dibole

The F1 vs. F2 formant plots for the five Dibole speakers of this study are found in Figures 4.28-4.32. Note that because there are three female speakers, their data are presented first. Like Ifè, Dibole has a seven vowel system with underlying [+ATR] mid vowels: /i e ɛ ɑ ɔ o u/[47]. Dibole mid-vowel harmony occurs at stem level with rightwards spreading to Final *–e*. (see § 2.2.1.2 for further detail). No known surface variants have been reported to occur.

Across speakers, there is a clear distinction in F1 between [+ATR] and [-ATR] mid vowels. There is also no apparent overlap for F1 between [-ATR] mid vowels and the low vowel for four of the five speakers. The only notable exception is speaker 1F-MN. The cross-height [+ATR] vowels, [i]/[e] and [u]/[o] present a different picture, with partial overlap at the edges of the spreads of these vowel pairs. This partial overlap is most noticeable among the female speakers, though also among the male speakers,

[47] Note that while Leitch 1996 has analyzed both Dibole and Mbosi as having privative RTR, [+ATR] and [-ATR] are used here for consistency and comparison across languages.

but to a much lesser degree. Also most noticeable among the female speakers is a differentiation between the F1 values for the tokens of [e] originating in the noun *ehese* ‘bone’ and those tokens originating in the verb *sesa* ‘admire imp.’ The F1 values for the [e] of *ehese* all clump at much lower F1 values than the [e] of *sesa*. Also noticeable in the speech of the three females as well as in the speech of one of the males, 5M-L, is a difference in F1 values for those tokens of [a] originating in the word *sala* ‘work imp.’ and those tokens originating in the word *asasi* ‘he did wrong’. The tokens of [a] from the word *asasi* have consistently lower F1 values than the tokens from *sala*.

Several of the speakers also exhibit overlap of F2 values for [ATR] harmony pairs [e]/[ɛ]. Again, this is most noticeable among the female speakers, although it may be seen to a lesser degree amongst the males also. There is also a degree of overlap for F2 between cross height vowels [i]/[e] and [u]/[o], especially noticeable among the males, though also to a degree with the female speakers.

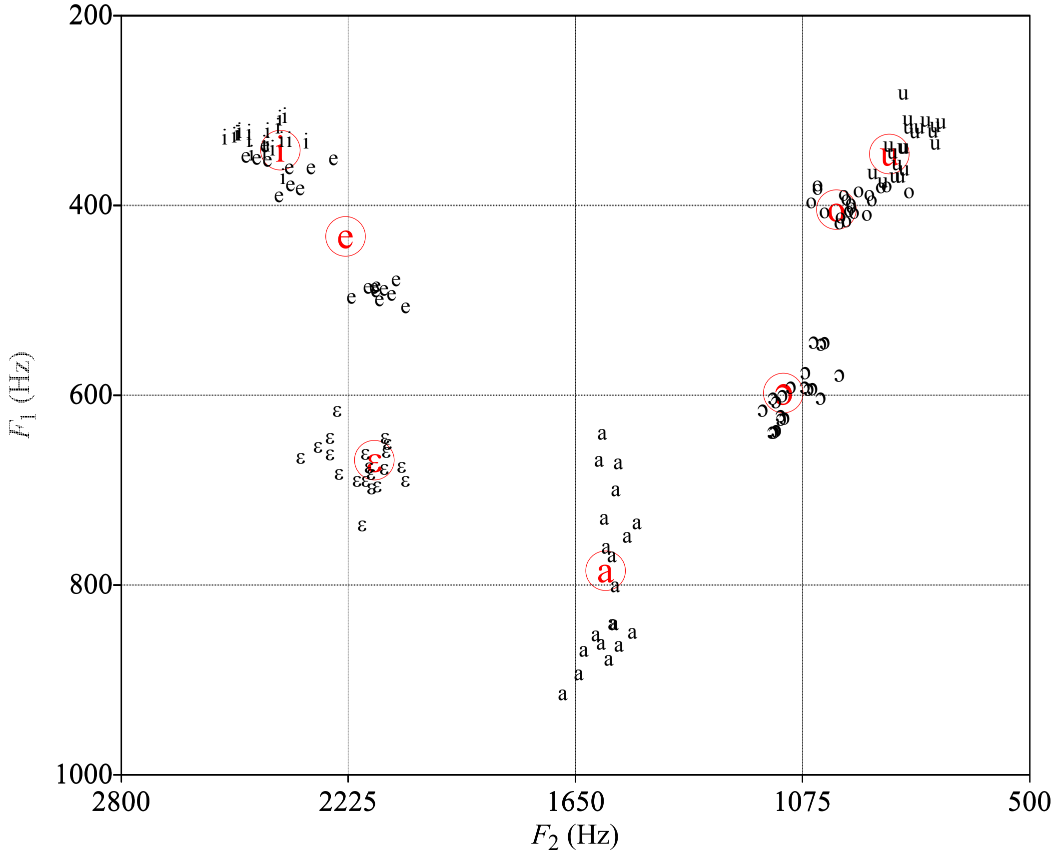


Figure 4.28: F1 vs. F2 vowel formant chart for Dibole speaker 1, female (1F-MN)

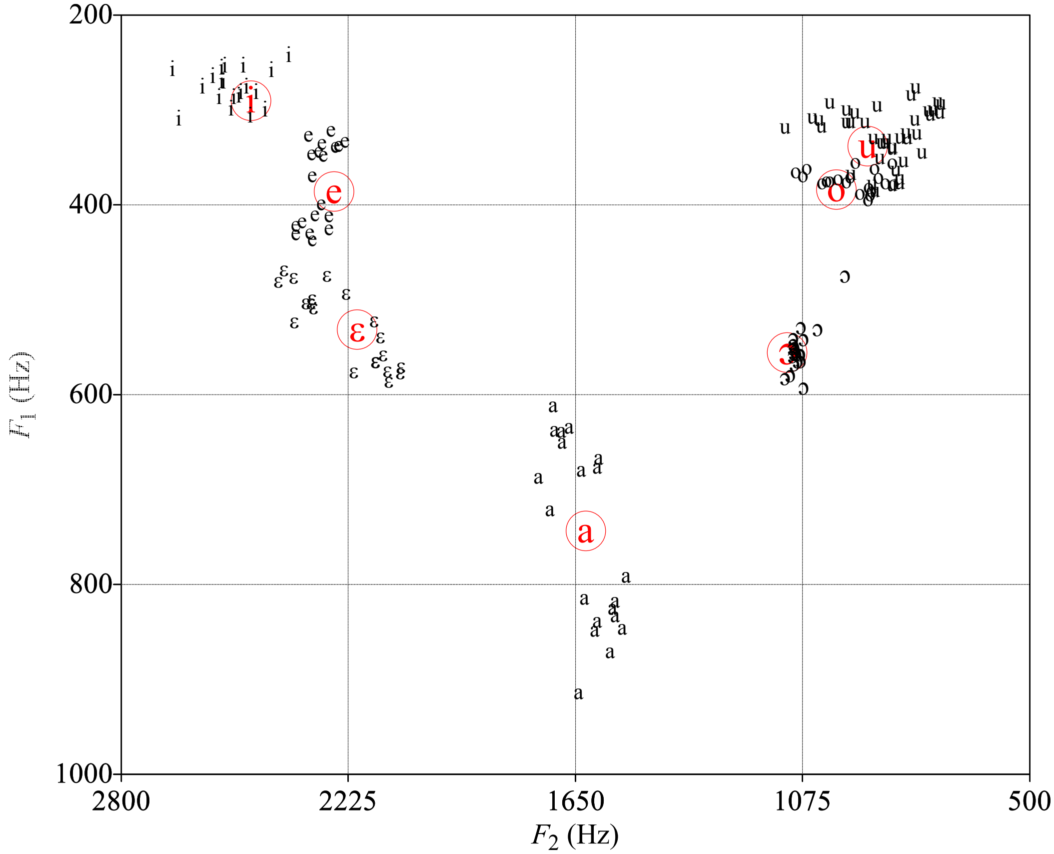


Figure 4.29: F1 vs. F2 vowel formant chart for Dibole speaker 2, female (2F-F)

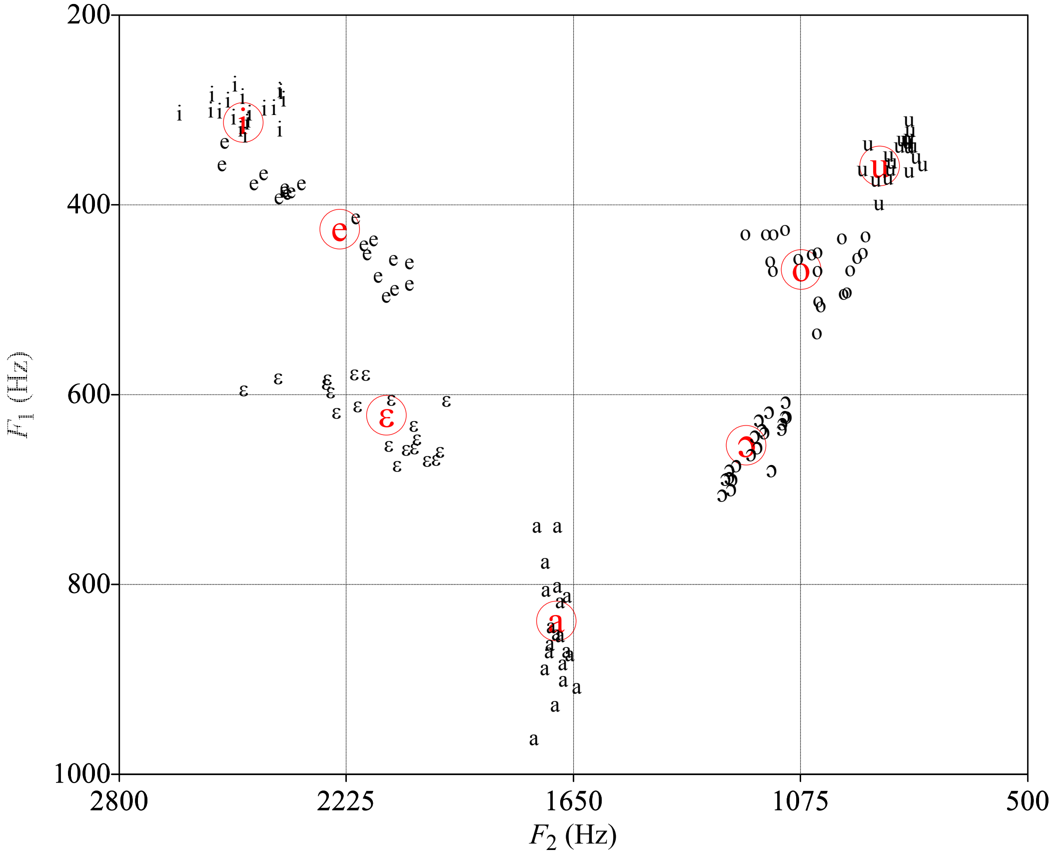


Figure 4.30: F1 vs. F2 vowel formant chart for Dibole speaker 3, female (3F-S)

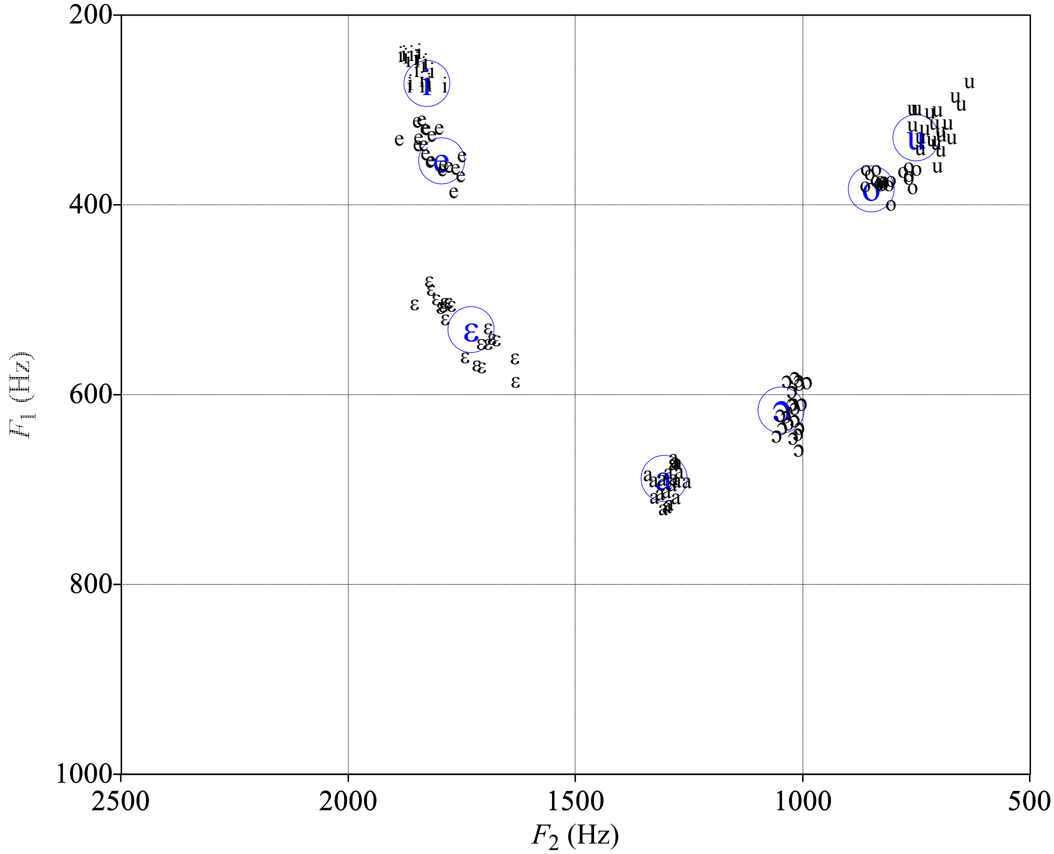


Figure 4.31: F1 vs. F2 vowel formant chart for Dibole speaker 4, male (4M-C)

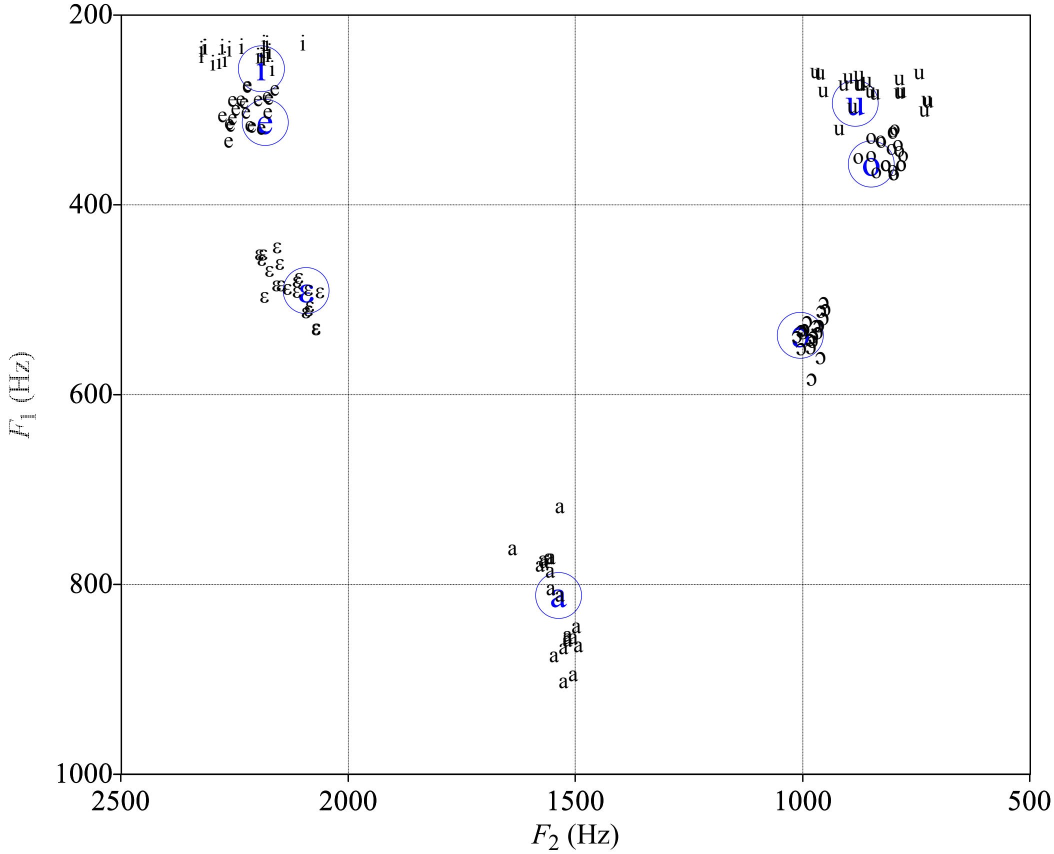


Figure 4.32: F1 vs. F2 vowel formant chart for Dibole speaker 5, male (5M-L)

The F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with both Gender and Vowel Group [F(1,392)=4.06 p=0.045]. The main effect of [ATR], is also significant [F(1,392)=1634.3 p=0.000]. These results suggest that there are differences in F1 means within the vowel pairs but that they are not consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] does not interact significantly with Vowel Group for four of the five speakers [1F-M $F(1,76)=5.99$; 2F-F $F(1,76)=3.54$; 3F-S $F(1,76)=0.475$; 5M-L $F(1,76)=59.51$], but does for the remaining male speaker 4M-C [$F(1,76)=32.64$ p=0.000]. The main effect of [ATR], however, is significant for all five speakers [1F-M $F(1,74)= 637.14$; 2F-F $F(1,93)= 528.53$; 3F-S $F(1,73)= 586.94$; 4M-C $F(1,72)= 1848.95$; 5M-L $F(1,78)= 1904.76$]. In all cases, $p=0.000$. [+ATR] vowels have significantly lower F1 means than their [-ATR] counterparts. These results suggest that F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, and that the effect is mostly consistent across vowel groups for every speaker.

To further investigate the Dibole vowel system, the F1 values of all the vowels of each Dibole speaker were submitted to a one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.23, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.23: Dibole F1 Mean Values by Vowel Group for Each Speaker

Vowel Group	Vowel Quality	Pooled Data	1F-MN	2F-F	3F-S	4M-C	5M-L
i	i [+ATR]	295	342	291	313	272	257
e	e [+ATR]	382	434	386	426	354	313
	ɛ [-ATR]	569	669	532	622	532	491
ɑ	ɑ [-ATR]	773	785	744	839	689	812
o	o [+ATR]	400	405	384	468	384	357
	ɔ [-ATR]	592	599	566	653	616	538
u	u [+ATR]	334	346	338	359	329	298

The main effect of Vowel Quality is significant for all speakers as well as for each Dibole speaker [Pooled $F(6,713)=992.73$; 1F-MN $F(6,136) = 327.7$; 2F-F $F(6,153) = 303.2$; 3F-S $F(6,133) = 562.6$; 4M-C $F(6,133) = 1327.3$; 5M-L $F(6,133) = 1309.6$]. In each case, p=0.000. Dibole presents a picture similar to that of Ifè where F1 means are significant for all vowels, whether [ATR] harmony pairs [e]/[ɛ], [o]/[ɔ] or cross-height pairs [i]/[e], [u]/[o].

Since there appears to be a difference between the F1 values of [e] and [a] when these vowels are followed by a [+ATR] final vowel as opposed to when they are followed by the [-ATR] low vowel, separate ANOVA were also run with F1 as the dependent factor and [ATR] value of the final vowel as the independent factor. The results for [a] were significant for each speaker, with the [a] before final [i] having a significantly lower F1 mean than [a] before [a] [1F-MN $F(1,18) = 65.6$; 2F-F $F(1,18) = 148.6$; 3F-S $F(1,18) = 24.8$; 4M-C $F(1,18) = 30.4$; 5M-L $F(1,18) = 85.4$]. In each case, $p=0.000$. The ANOVA comparing tokens of [e] produced similar results. For each speaker, [e] before [e] has a significantly lower F1 mean than [e] before [a] [1F-MN *F*(1,18) = 468; 2F-F *F*(1,18) = 137.7; 3F-S *F*(1,18) = 74.12; 4M-C *F*(1,18) = 56.9; 5M-L *F*(1,18) = 51.2]. In each case, *p*=0.000.

The relative importance of these findings will be discussed more fully in §5.2.7 of the language summaries where they will be compared with the results of the other acoustic measures.

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). Unlike the results for F1, [ATR] does not interact significantly with either Gender or Vowel Group [*F*(1,392)=0.683] or with Gender alone [*F*(1,392)=1.16]. [ATR] does interact significantly with Vowel Group [*F*(1,392)=101.66 p=0.000]. And the main effect of [ATR] is also significant [*F*(1,392)=10.45 p=0.001], suggesting that there may be differences in F2 means within the vowel pairs and that they are consistent across gender but not across vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for all speakers [1F-M *F*(1,76)= 31.72; 2F-F *F*(1,76)= 39.23; 3F-S *F*(1,76)= 26.0; 4M-C *F*(1,76)= 218.82; 5M-L *F*(1,76)= 323.59]. In all cases, *p*=0.000. The main effect of [ATR], however, is significant for only the two male speakers [4M-C *F*(1,76)=57.42; and 5M-L *F*(1,76)=23.57; *p*=0.000] and not for the females [1F-M *F*(1,76)= 2.88; 2F-F *F*(1,76)=

5.0; 3F-S $F(1,76)= 0.2$]. These results suggest that any significant differences are not consistent across vowel pairs.

For a clearer picture of the Dibole vowel system, the F2 values of all speakers and for each Dibole speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.24, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

As with F1, the main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled $F(6,713)= 1391.29$; 1F-MN $F(6,136) = 1726.8$; 2F-F $F(6,153) = 1946.7$; 3F-S $F(6,133) = 519.4$; 4M-C $F(6,133) = 3570$; 5M-L $F(6,133) = 3793.9$]. In each case, $p=0.000$. As was predicted from the scatterplots, F2 fails to distinguish the harmony pair [e]/[ɛ] for two of the female speakers, 2F-F and 3F-S. F2 also fails to distinguish cross-height vowels [i]/[e] for both male speakers as well as for the [u]/[o] pair of speaker 5M-L. Nonetheless, F2 mean differences are significant for both harmony pairs in three of the five speakers.

Table 4.24: Dibole F2 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1F-MN	2F-F	3F-S	4M-C	5M-L
i	i [+ATR]	2274	2396	2470	2485	1827[1]	2192[1]
e	e [+ATR]	2142	2231	2261	2240	1795[1]	2183[1]
	ɛ [-ATR]	2062	2159	2201	2124	1731	2093
ɑ	ɑ [-ATR]	1546	1573	1624	1692	1306	1538
o	o [+ATR]	950	989	989	1074	849	850[2]
	ɔ [-ATR]	1101	1124	1114	1213	1048	1006
u	u [+ATR]	864	854	910	874	751	885[2]

4.2.8 Mbosi

The F1 vs. F2 formant plots for the five Mbosi speakers of this study are found in Figures 4.33-4.37. Mbosi has the same vowel inventory as Dibole: a seven vowel system with underlying [+ATR] mid vowels: /i e ɛ ɑ ɔ o u/. Like Dibole, lexical mid-vowel harmony occurs at stem level with rightwards spreading to Final *–e*. There is also post-lexical leftward spreading. In such cases, [a] also induces [-ATR] harmony (see §2.2.1.2 for further detail). No known surface variants occur.

Across speakers, there is a clear distinction in F1 between [+ATR] and [-ATR] mid vowels. There is also no apparent overlap for F1 between [-ATR] mid vowels and the low vowel for any of the speakers. Cross-height [+ATR] vowels also exhibit little to no overlap in F1 values, with 2M-Le being the only speaker whose back vowels [u] and [o] partially overlap at the upper and lower extremes of their F1 frequencies. Speaker

5F-M exhibits similar behavior in her low vowel, little to no overlap between the ten tokens originating from the word *sala* and those from *tara*. But unlike Dibole, any differences between the F1 values of [a] cannot be contributed to a following [+ATR] vowel since both of these words end in [a].

There appears to be considerable overlap of F2 values for the front and back mid-vowel pairs for all speakers. In addition, for two of the male speakers, 1M-C and 3M-O, the higher F2 frequencies for [u] cause the vowel to be somewhat centralized. Two of the speakers, 2M-Le and 4F-Ly, also have overlapping F2 values for cross-height [u] and [ɔ].

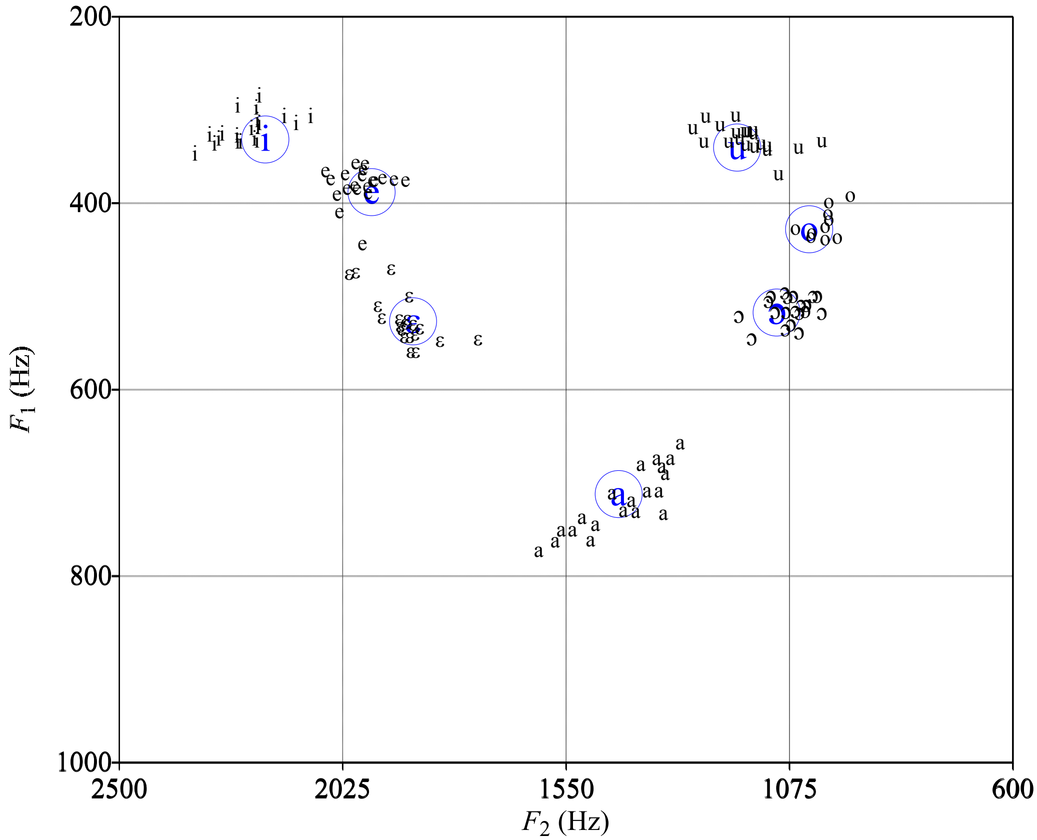


Figure 4.33: F1 vs. F2 vowel formant chart for Mbosi speaker 1, male (1M-C)

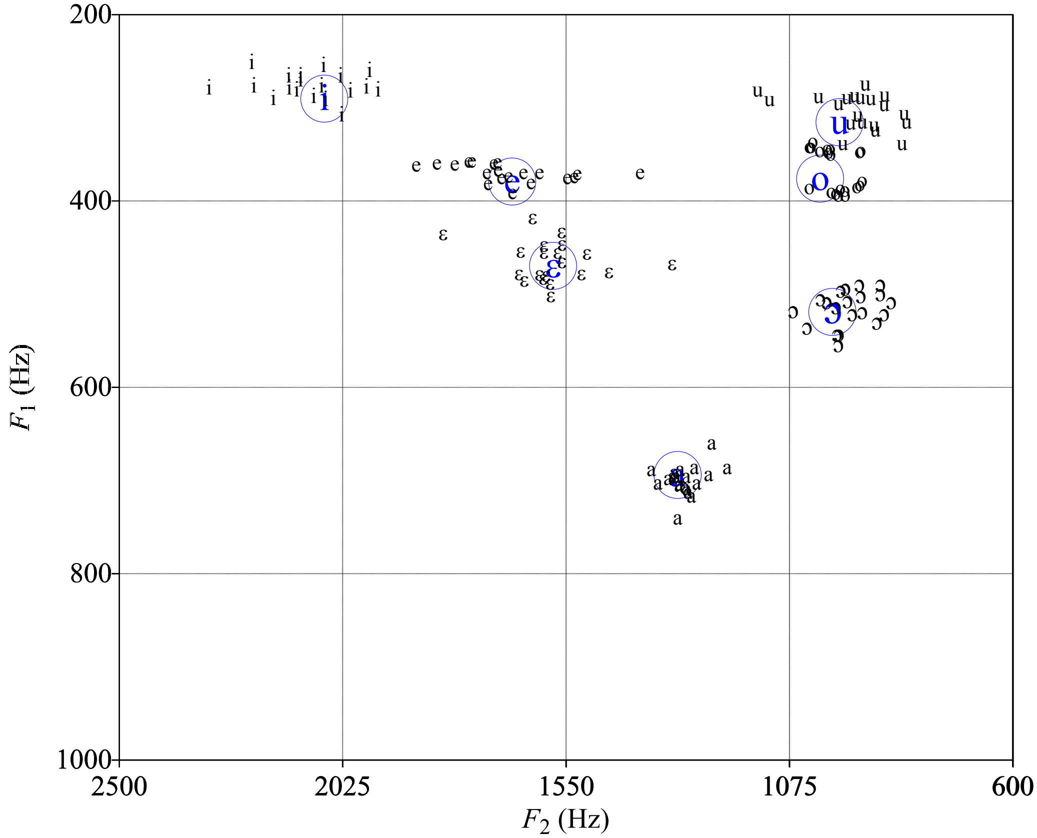


Figure 4.34: F1 vs. F2 vowel formant chart for Mbosi speaker 2, male (2M-Le)

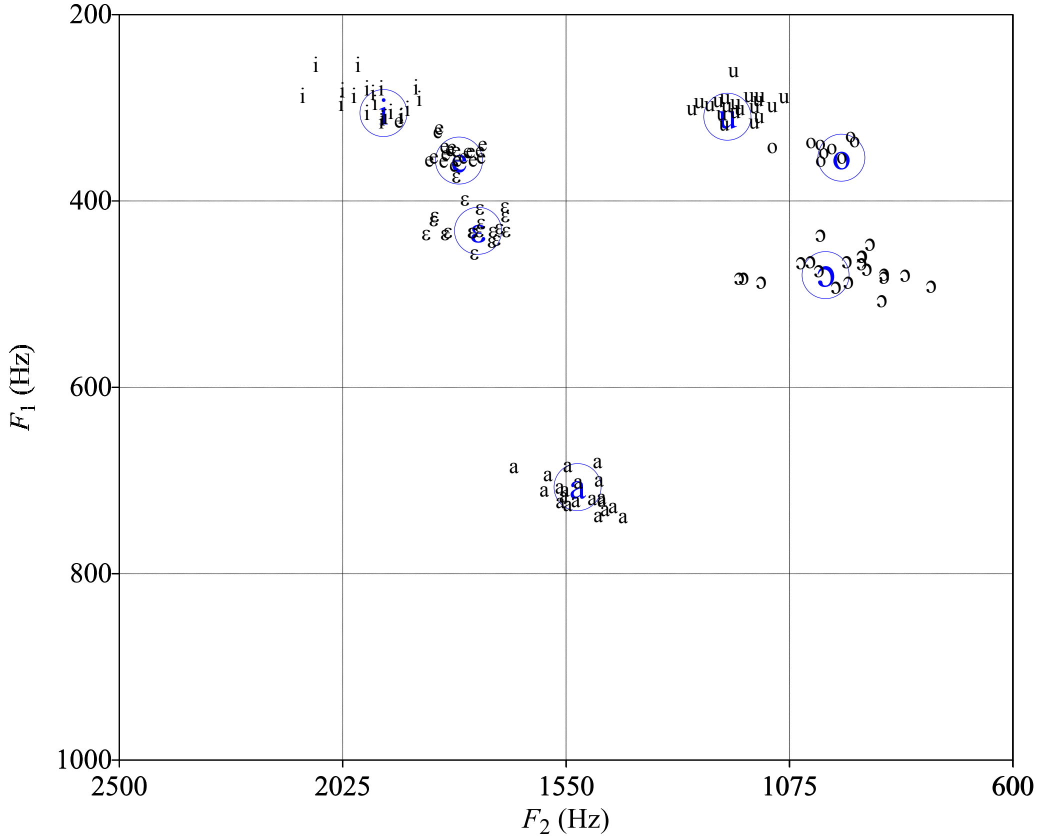


Figure 4.35: F1 vs. F2 vowel formant chart for Mbosi speaker 3, male (3M-O)

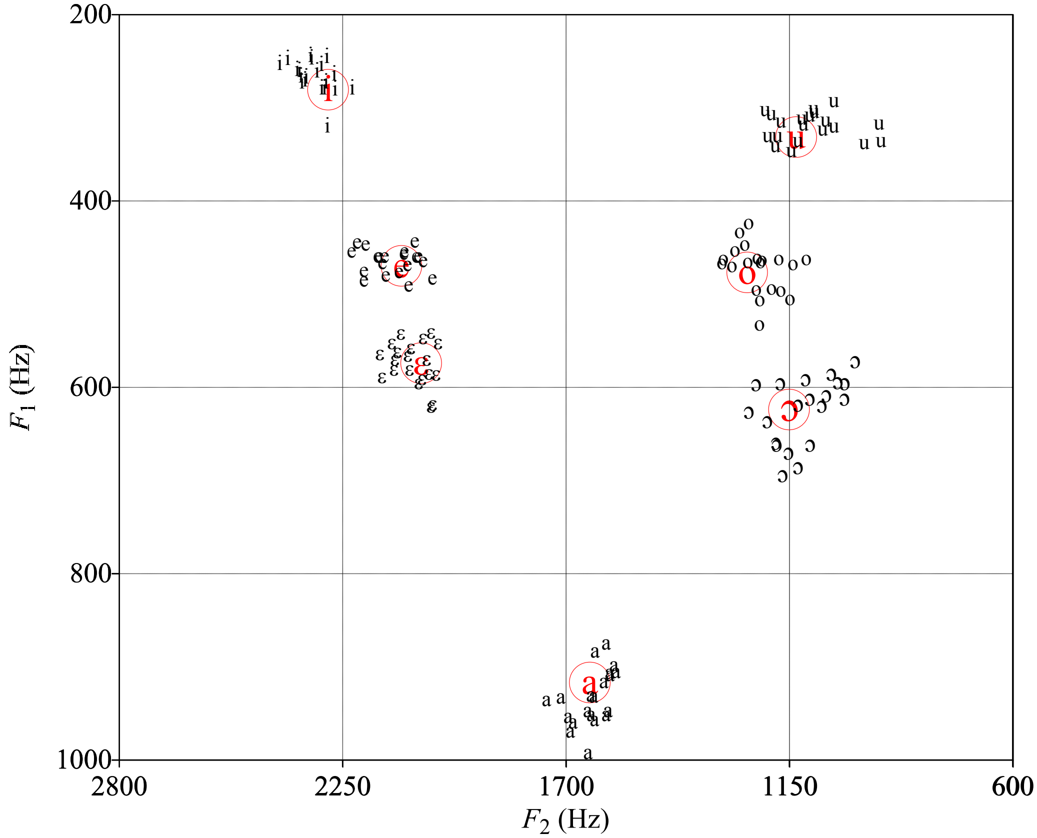


Figure 4.36: F1 vs. F2 vowel formant chart for Mbosi speaker 4, female (4F-Ly)

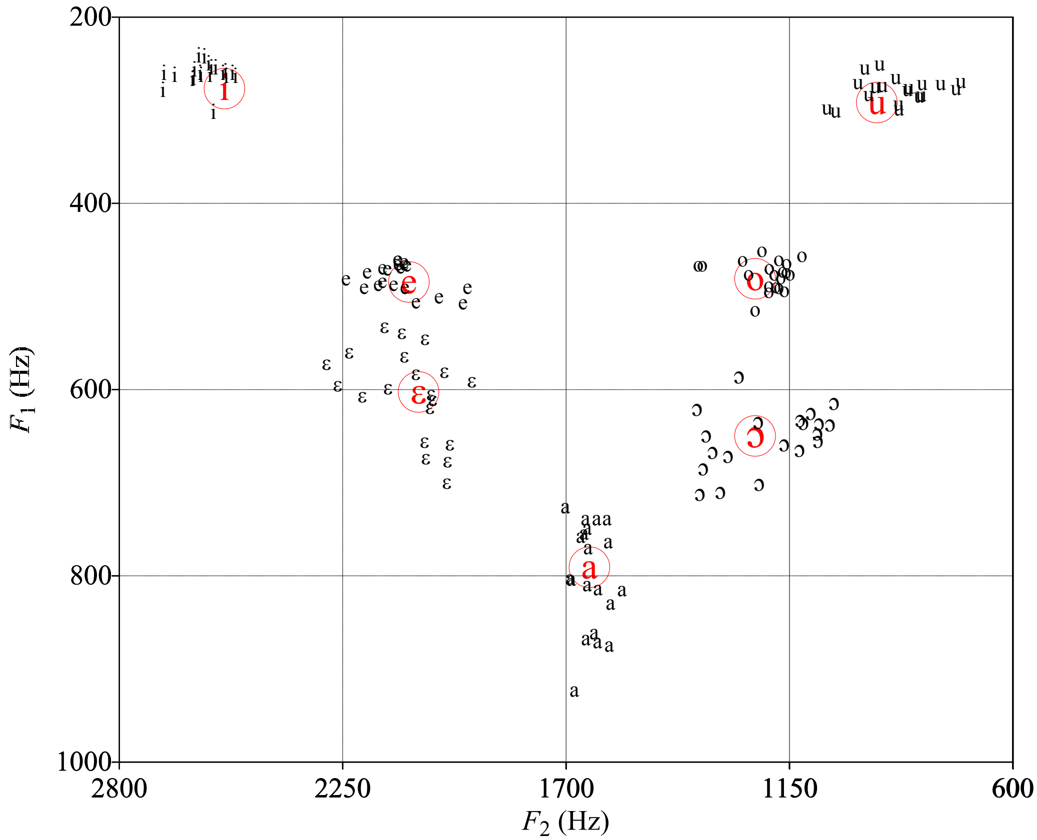


Figure 4.37: F1 vs. F2 vowel formant chart for Mbosi speaker 5, female (5F-M)

The F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] does not interact significantly with both Gender and Vowel Group [$F(1,372)=2.83$ $p=0.094$], but does interact significantly with Gender [$F(1,372)=10.03$ $p=0.002$] and with Vowel Group [$F(1,372)=22.79$ $p=0.000$]. The main effect of [ATR] is also significant [$F(1,372)=1367.0$ $p=0.000$]. These results suggest that there are differences in F1 means within the vowel pairs but that they are not consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for all speakers [1M-C $F(1,66)=26.17$, $p=0.000$; 2M-Le $F(1,76)=42.97$ $p=0.000$; 3M-O $F(1,66)=49.16$ $p=0.000$; 4F-Ly $F(1,76)=13.07$ $p=0.001$; 5F-M $F(1,76)=8.12$, $p=0.006$]. The main effect of [ATR] is also significant for all five speakers [1M-C $F(1,66)= 564.36$; 2M-Le $F(1,76) = 853.98$; 3M-O $F(1,66)=773.11$; 4F-Ly $F(1,76)=475.02$; 5F-M $F(1,76)=332.44$]. In all cases, $p=0.000$. [+ATR] vowels have significantly lower F1 means than their [-ATR] counterparts. These results suggest that F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, but that the effect is not consistent across vowel groups.

To further investigate the Mbosi vowel system, the F1 values of all the vowels of each Mbosi speaker were submitted to a one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.25, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.25: Mbosi F1 Mean Values by Vowel Group for Each Speaker

Vowel Group	Vowel Quality	Pooled Data	1M-C	2M-Le	3M-O	4F-Ly	5F-M
i	i [+ATR]	297	332	290	306	281	277
e	e [+ATR]	416	389	379	357	470	484
	ɛ [-ATR]	521	527	470	432	574	603
ɑ	ɑ [-ATR]	764	713	694	707	917	791
o	o [+ATR]	431	429	376	354	477	481
	ɔ [-ATR]	558	518	519	480	624	650
u	u [+ATR]	318	341	316	310	332	292

The main effect of Vowel Quality is significant for all speakers as well as for each Mbosi speaker [Pooled $F(6,671)=715.07$; 1M-C $F(6,123) = 850.6$; 2M-Le $F(6,132) = 1360.3$; 3M-O $F(6,123) = 1789.3$; 4F-Ly $F(6,133) = 1680.3$; 5F-M $F(6,132) = 715.1$]. In each case, $p=0.000$. Mbosi presents a picture similar to that of Dibole where F1 means are significant for all vowels, whether [ATR] harmony pairs [e]/[ɛ], [o]/[ɔ] or cross-height pairs [i]/[e], [u]/[o].

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). Unlike the results for F1, [ATR] interacts significantly with both Gender and Vowel Group [$F(1,372)=5.45$ $p=0.02$]. The main effect of [ATR] is also significant [$F(1,372)= 9.66$ $p=.002$], suggesting that there may be differences in F2 means within the vowel pairs but that they are not consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for only one speaker [1M-C $F(1,66)=50.50$ $p=0.000$] but not for the other speakers [2M-Le $F(1,76) = 1.49$; 3M-O $F(1,66) = 2.08$; 4F-Ly $F(1,76)=3.69$; 5F-M $F(1,76)= .292$]. Likewise, the main effect of [ATR] is significant for only two of the speakers, one male and one female [2M-Le $F(1,76)=11.73$ $p=0.001$ and 4F-Ly $F(1,76)=31.98$ $p=0.000$] and not for the other two males and one female [1M-C $F(1, 66)=.718$; 3M-O $F(1, 66)=.02$; 5F-M $F(1,76)= .431$]. These results suggest that any significant differences are not consistent across gender.

For a clearer picture of the Mbosi vowel system, the F2 values of all speakers and for each Mbosi speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.26, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

As with F1, the main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled $F(6,671)=722.82$; 1M-C $F(6,123) = 1160.5$; 2M-Le $F(6,132) = 565.8$; 3M-O $F(6,123) = 379$; 4F-Ly $F(6,133) = 1451.6$; 5F-M $F(6,132) = 1113.2$]. In each case, $p=0.000$. As was predicted from the scatterplots, F2 is an unreliable predictor of [ATR]. F2 fails to distinguish both harmony pairs [e]/[ɛ] and [o]/[ɔ] for two speakers, 3M-O and 5F-M, [o]/[ɔ] for speaker 2M-Le, and [e]/[ɛ] for speaker 4F-Ly. F2 mean differences for cross-height vowels [u]/[ɔ] are also not statistically significant for speakers 2M-Le and 4F-Ly. Overall, F2 mean differences are less robust for distinguishing harmony pairs in the Mbosi data than in Dibole.

Table 4.26: Mbosi F2 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-C	2M-Le	3M-O	4F-Ly	5F-M
i	i [+ATR]	2205	2189	2064	1938	2285	2541
e	e [+ATR]	1919	1963	1664	1777	2105	2086
	ɛ [-ATR]	1861	1875	1577	1736	2056	2063
ɑ	ɑ [-ATR]	1508	1438	1312	1525	1641	1642
o	o [+ATR]	1124[2]	1032	1009[1]	964	1253	1234
	ɔ [-ATR]	1090[2]	1102	968[1]	997	1150[1]	1234
u	u [+ATR]	1086[2]	1186	966[1]	1206	1132[1]	934

4.2.9 Mbonge

The F1 vs. F2 formant plots for the five Mbonge speakers of this study are found in Figures 4.38-4.42. Mbonge, one of two Oroko dialects presented in this study, is reported to have the same vowel inventory as Ifè, Dibole and Mbosi: a seven vowel system with underlying [+ATR] mid vowels: /i e ɛ ɑ ɔ o u/. Similar to Dibole, Mbonge lexical mid-vowel harmony occurs at stem level with rightwards spreading to the final vowel (see § 2.2.1.1.1 for further detail).

The scatterplots of F1 values for the seven vowels of most of the Mbonge speakers are similar to those seen in other seven-vowel languages so far: little to no overlap of mid-vowel pairs, but a slight tendency for the [+ATR] high and mid vowels to overlap, respectively, at the higher and lower ends of their frequencies. Speaker 3M-P presents exceptional behavior, with notable overlap of F1 values for [i] and [e].

However, Mbonge does present a more complicated picture of the use of vowel space than seen to this point. Most of the complication appears to be along the F2 dimension, where there is a considerable spread of [+ATR] tokens [i e o u]. This is most noticeable in the back vowels of the male speakers as well as female speaker 5F-B. It is also true but to a lesser degree with the front vowels and most noticeable in the tokens for [i] of male speaker 3M-P.

This spread of the tokens was unforeseen at the time of recording but is due to two factors: the rate at which a speaker uttered the words of the wordlist and the quality of the consonant in the coda of the root. On the mean, the four speakers who have a wide spread of F2 values for the [+ATR] vowels in particular uttered these vowels at twice the speed as speaker 4F-J (.09-.1 sec. vs. .16-.22 sec.) Those vowel tokens which are embedded between two voiceless alveolar consonants (typically [sVs] or [tVt]), tend to have overall lower mean F2 values. Though it is not possible to evaluate which of these two factors plays a more significant role in the centralization of the tokens for the four speakers in question, it is noteworthy that speaker 4F-J also shows this tendency for her tokens of [e]. Those tokens uttered in a [tVt] context have a lower F2 mean than those uttered in a [kVk] context.

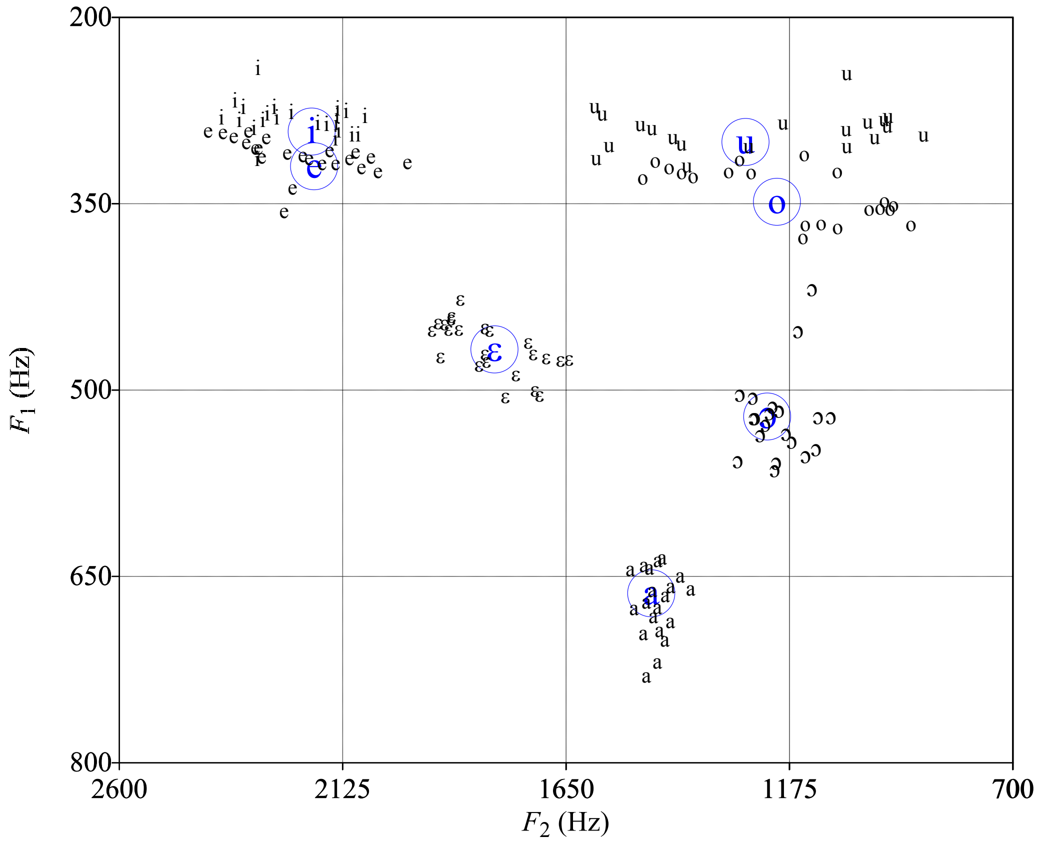


Figure 4.38: F1 vs. F2 vowel formant chart for Mbonge speaker 1, male (1M-Jo)

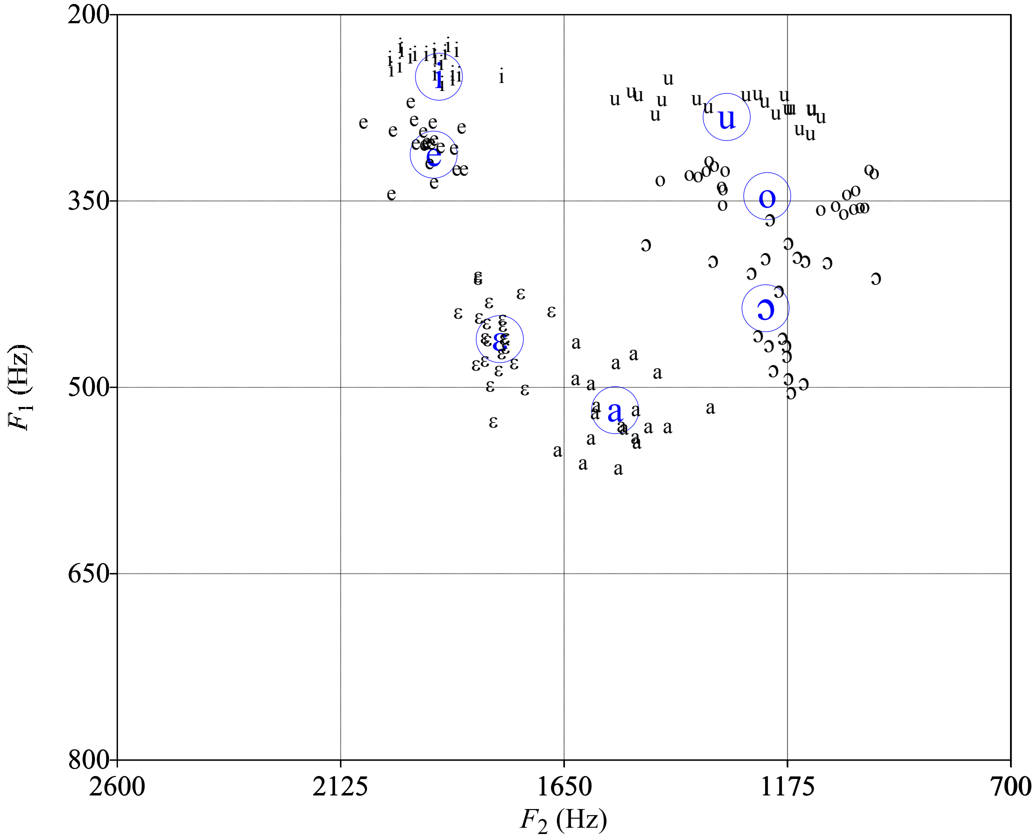


Figure 4.39: F1 vs. F2 vowel formant chart for Mbonge speaker 2, male (2M-J)

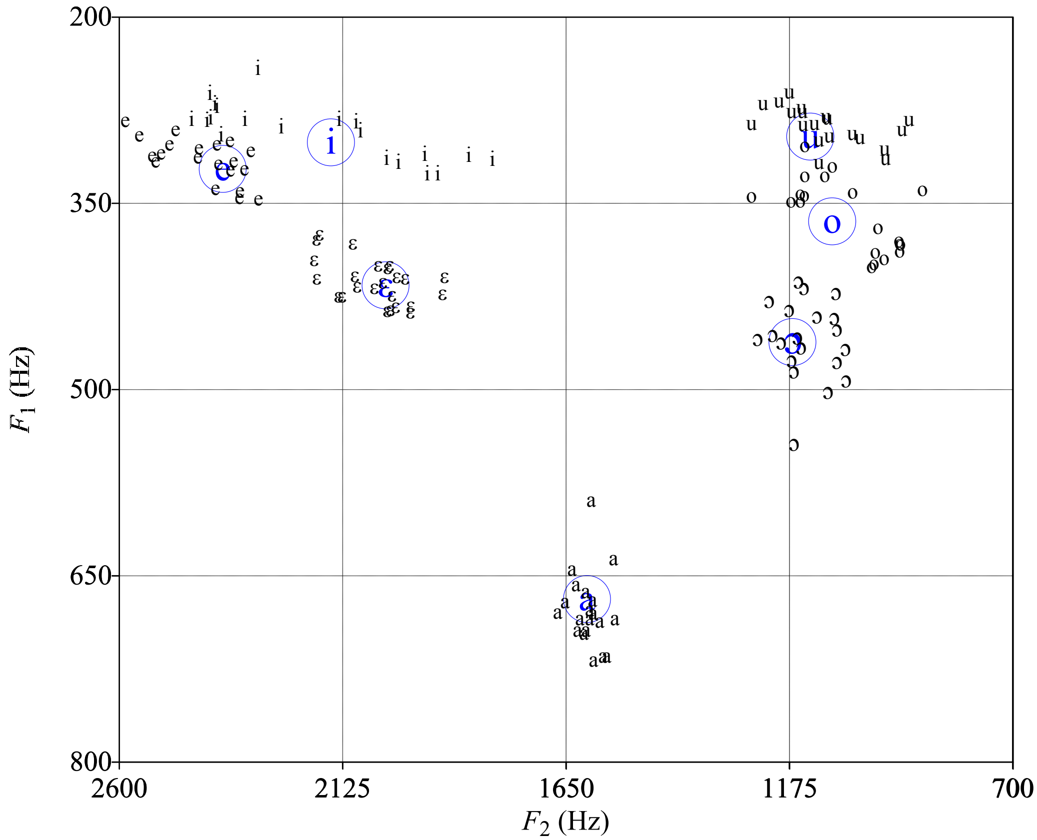


Figure 4.40: F1 vs. F2 vowel formant chart for Mbonge speaker 3, male (3M-P)

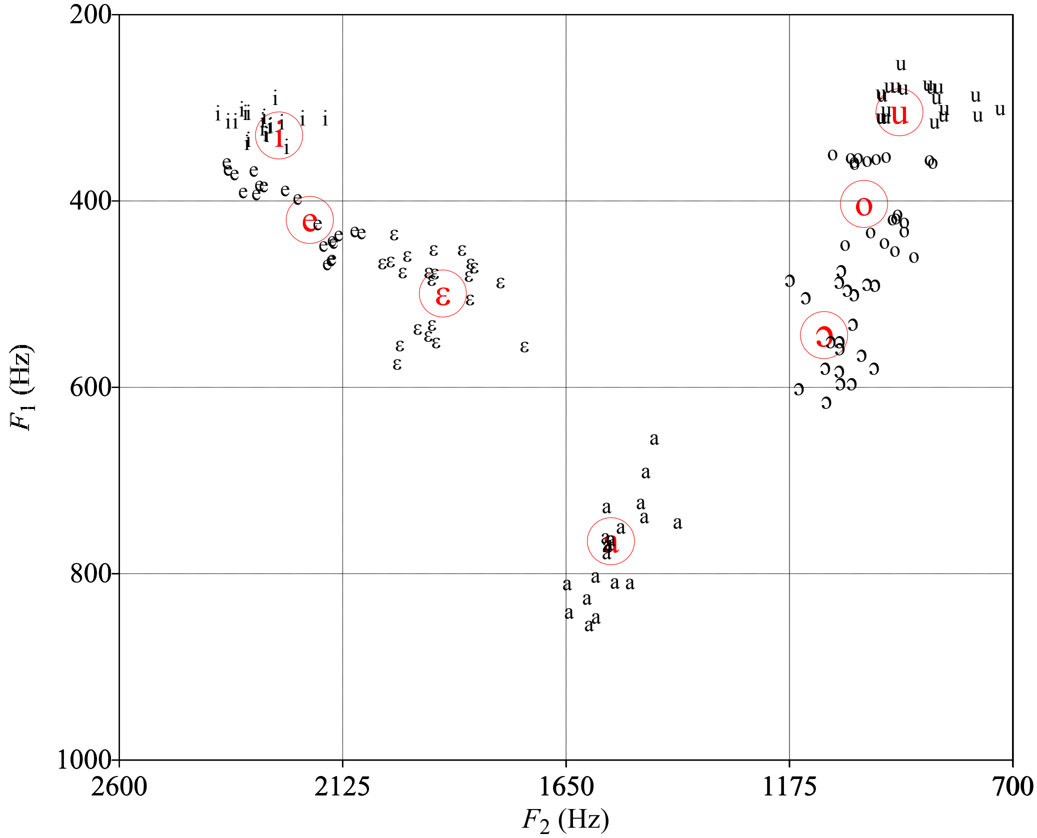


Figure 4.41: F1 vs. F2 vowel formant chart for Mbonge speaker 4, female (4F-J)

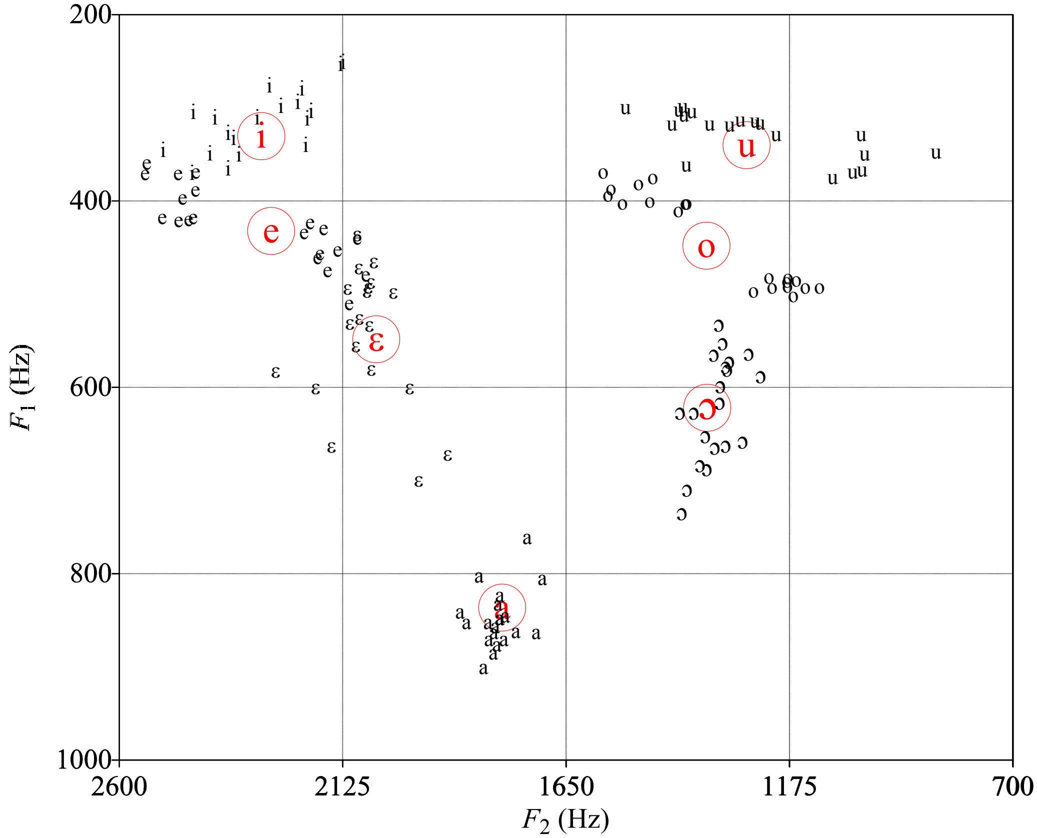


Figure 4.42: F1 vs. F2 vowel formant chart for Mbonge speaker 5, female (5F-B)

The F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with both Gender and Vowel Group [$F(1,402)=17.67$, $p=0.000$]. The main effect of [ATR] is also significant [$F(1,402)=875.22$ $p=0.000$]. These results suggest that there are differences in F1 means within the vowel pairs but that they are not consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for two speakers, one male and one female [2M-J $F(1,79)=23.02$ $p=0.000$ and 4F-J $F(1,78)=12.21$ $p=0.001$] but not for the rest [1M-Jo $F(1,82)=6.71$; 3M-P $F(1,76)=.257$; 5F-B $F(1,75)=5.45$]. The main effect of [ATR], however, is significant for all five speakers [1M-Jo $F(1,82)=1058.24$; 2M-J $F(1,79)= 387.36$; 3M-P $F(1,76)= 316.04$; 4F-J $F(1,78)= 155.2$; 5F-B $F(1,75)= 142.15$]. In all cases, $p=0.000$. [+ATR] vowels have significantly lower F1 means than their [-ATR] counterparts. These results confirm that F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, but that the effect is not consistent across vowel groups or gender.

To further investigate the Mbonge vowel system, the F1 values of all the vowels of each Mbonge speaker were submitted to a one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.27, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.27: Mbonge F1 Mean Values by Vowel Group for Each Speaker

Superscript numbers indicate cross-height vowel means which are not significantly different

Vowel Group	Vowel Quality	Pooled Data	1M-Jo	2M-J	3M-P	4F-J	5F-B
i	i [+ATR]	300	292	250	301[1]	330	331
e	e [+ATR]	360	316	313	322[1]	421	432
	ɛ [-ATR]	475	470	461	414	500	549
ɑ	ɑ [-ATR]	691	664	519	669	765	837
o	o [+ATR]	382	348	346	365	403	448
	ɔ [-ATR]	517	521	437	462	544	622
u	u [+ATR]	304	300	283	296	305	340

The overall effect of vowel quality is significant for each Mbonge speaker [Pooled $F(6,709) = 461.87$; 1M-Jo $F(6,136) = 916$; 2M-J $F(6,136) = 358.5$; 3M-P $F(6,133) = 648.2$; 4F-J $F(6,135) = 368.6$; 5F-B $F(6,131) = 303.9$]. In each case, $p=0.000$. Mbonge presents a picture similar to that seen for other seven-vowel languages presented so far, where F1 means are distinct for all vowels, whether [ATR] harmony pairs [e]/[ɛ], [o]/[ɔ] or cross-height pairs [i]/[e], [u]/[o]. The notable exception is speaker 3M-P, where the differences in the mean F1 values for [i] and [e] are not significant within the overall model. A one-way ANOVA for the F1 values of these vowels shows a significant difference between their means [$F(1,38) = 12.21$, $p=0.001$]. Given a larger sample of this speaker's speech, it is quite possible that the differences in F1 means for these two vowels would be more robust within the overall model.

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). Unlike the results for F1, [ATR] does not interact significantly with both Gender and Vowel Group [$F(1,402)=.336$]. The main effect of [ATR], however is significant [$F(1,402)=62.38$ $p=0.000$], suggesting that there may be differences in F2 means within the vowel pairs and that they are likely to be consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for all five speakers [1M-Jo $F(1,82)=66.56$; 2M-J $F(1,79)=12.44$; 3M-P $F(1,76)=142.5$; 4F-J $F(1,78)=143.91$; 5F-B $F(1,75)=15.9$]. In each case, $p=0.000$. Likewise, the main effect of [ATR] is significant all speakers, [1M-Jo $F(1,82)= 53.58$; 2M-J $F(1,79)= 11.28$; 3M-P $F(1,76)= 51.79$; 4F-J $F(1,78)= 41.64$; 5F-B $F(1,75)= 16.34$]. In each case, $p=0.000$. These results suggest that any significant differences in F2 are not consistent across vowel groups.

For a clearer picture of the Mbonge vowel system, the F2 values of all speakers and for each Mbonge speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.28, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

As with F1, the main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled $F(9,709) = 835.58$; 1M-Jo $F(6,136) = 232.1$; 2M-J $F(6,136) = 229.5$; 3M-P $F(6,133) = 538.2$; 4F-J $F(6,135) = 1470.8$; 5F-B $F(6,131) =$

235.1]. In each case, p=0.000. But as predicted from the scatterplots where considerable overlap of F2 values occurs among the back vowels, F2 is an unreliable predictor of [ATR]. F2 fails to distinguish harmony pairs [o]/[ɔ] for the four speakers whose tokens were uttered more rapidly than 4F-J. Indeed, there are no significant differences among the mean values for F2 for the relevant pairs of high and mid back vowels for these four speakers. Additionally, F2 mean differences fail to differentiate between cross-height front vowels, [i]/[e] in three of the four rapid speakers. F2 does not appear to be a reliable measure of vowel quality in Mbonge rapid speech. However, since F2 mean differences are significant for all the vowels produced by speaker 4F-J, it may be surmised that in more careful/slower speech, significant differences would resurface.

Table 4.28: Mbonge F2 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-Jo	2M-J	3M-P	4F-J	5F-B
i	i [+ATR]	2163^1	2190^1	1916^1	2150	2260	2298^1
e	e [+ATR]	2192^1	2184^1	1927^1	2380	2194	2277^1
	ɛ [-ATR]	1914	1792	1786	2038	1912	2053
ɑ	ɑ [-ATR]	1591	1468	1541	1605	1554	1785
o	o [+ATR]	1173^2	1201^2	1217^2	1083^2	1016	1351^2
	ɔ [-ATR]	1212^2	1222^2	1221^2	1168^2	1100	1349^2
u	u [+ATR]	1180^2	1268^2	1304^2	1130^2	940	1265^2

4.2.10 Londo

The F1 vs. F2 formant plots for the five Londo speakers of this study are found in Figures 4.43-4.47. Londo, the second of the two Oroko dialects presented in this study, has the same vowel inventory as Mbonge, Ifè, Dibole and Mbosi: a seven vowel system with underlying [+ATR] mid vowels: /i e ɛ ɑ ɔ o u/. Similar to Mbosi, Londo lexical mid-vowel harmony occurs at stem level with rightwards spreading to final *–e*. There is also leftward spreading onto prefixes. Unlike Mbosi, [a] does not induce [-ATR] harmony (see § 2.2.1.1.1 for further detail). No known surface variants occur.

Londo presents a similar picture of the use of vowel space as Mbonge. That is, the scatterplots of F1 values present little to no overlap of mid-vowel pairs, but a tendency for the [+ATR] high and mid vowels to overlap, respectively, at the higher and lower ends of their frequencies. This effect is most notable for male speakers, with the back pair [u]/[o] showing considerable overlap in the results for 2M-W and in both pairs for speaker 3M-I. In addition, F2 values appear to also be sensitive to the length of the target vowel and to the quality of the consonants between which it is embedded. The centralization and spread of F2 values is most noticeable in formant display of speaker 1M-CE, whose tokens were uttered at a rate 25-40% quicker than the other speakers.

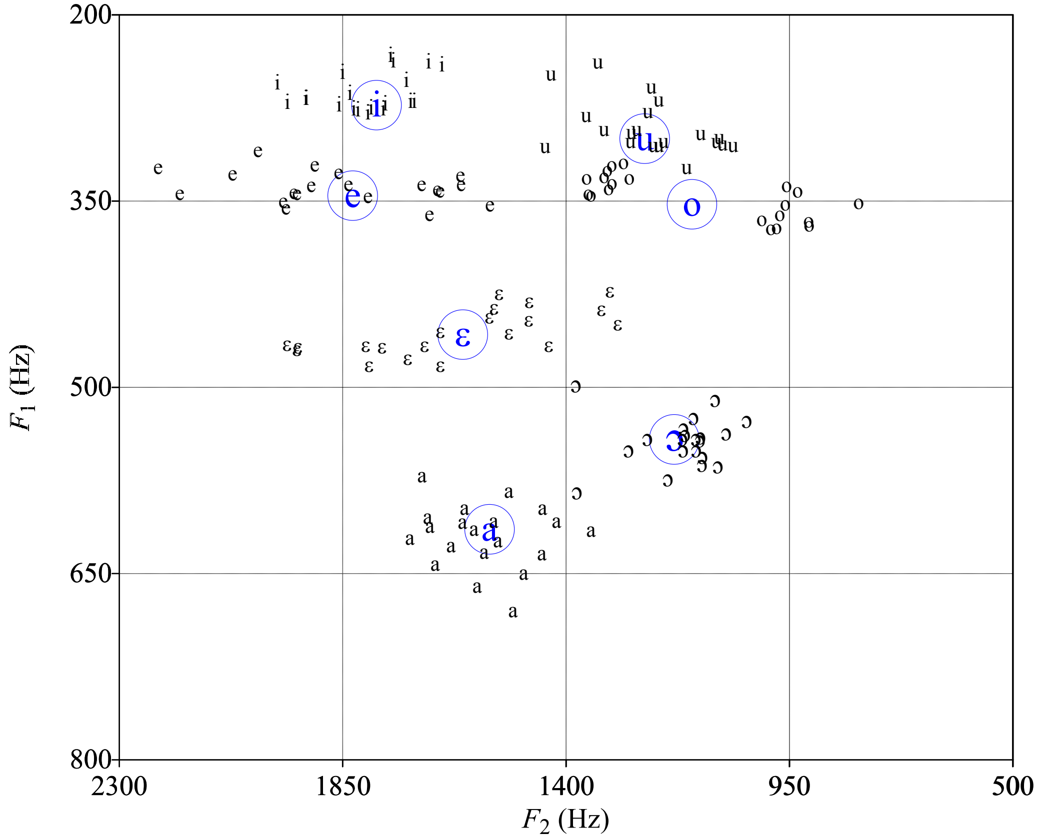


Figure 4.43: F1 vs. F2 vowel formant chart for Londo speaker 1, male (1M-CE)

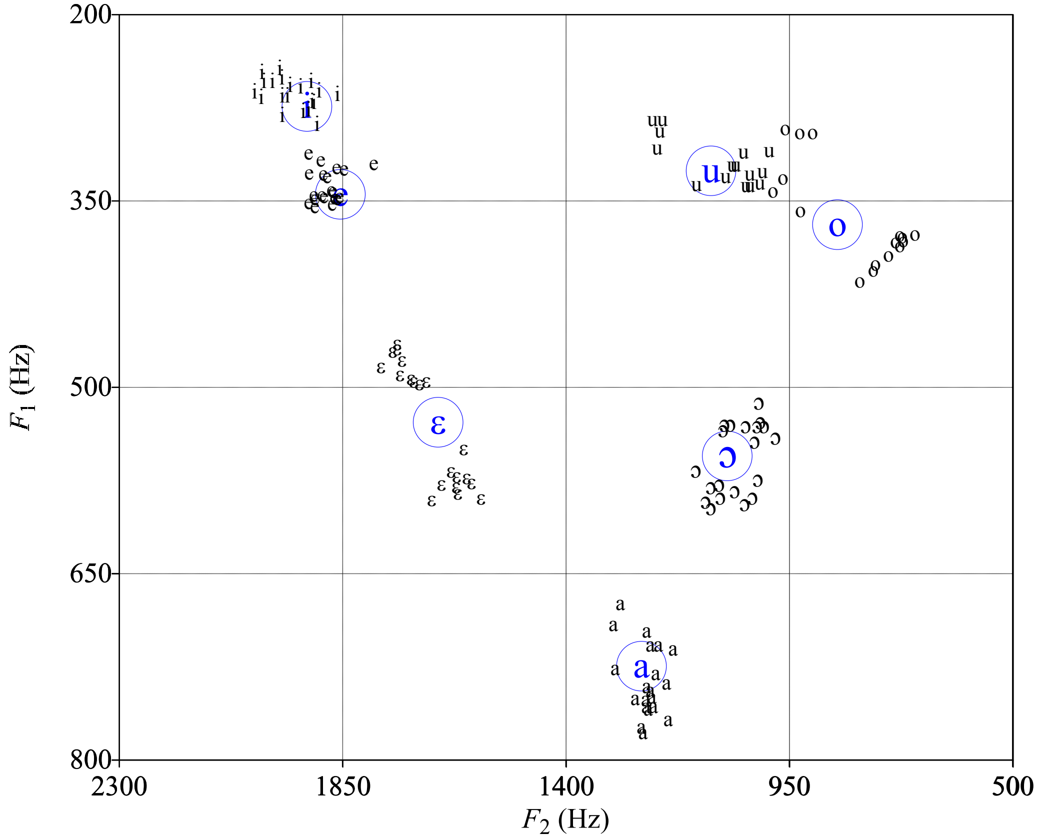


Figure 4.44: F1 vs. F2 vowel formant chart for Londo speaker 2, male (2M-W)

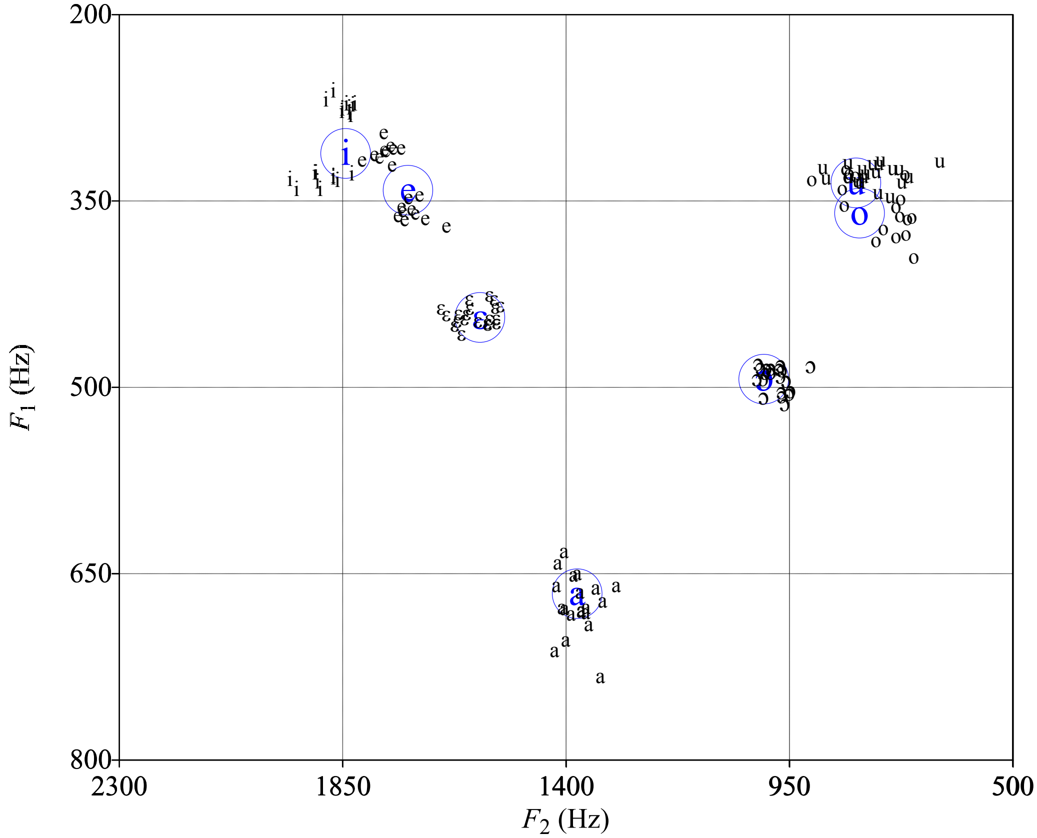


Figure 4.45: F1 vs. F2 vowel formant chart for Londo speaker 3, male (3M-I)

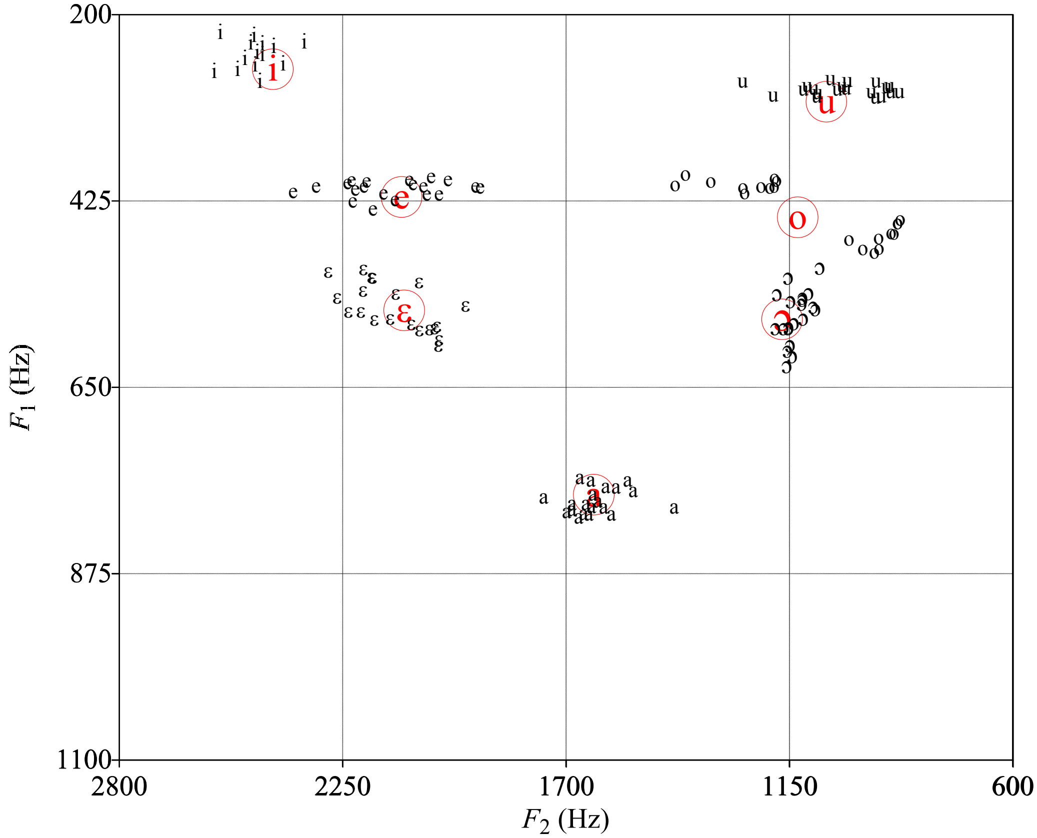


Figure 4.46: F1 vs. F2 vowel formant chart for Londo speaker 4, female (4F-M)

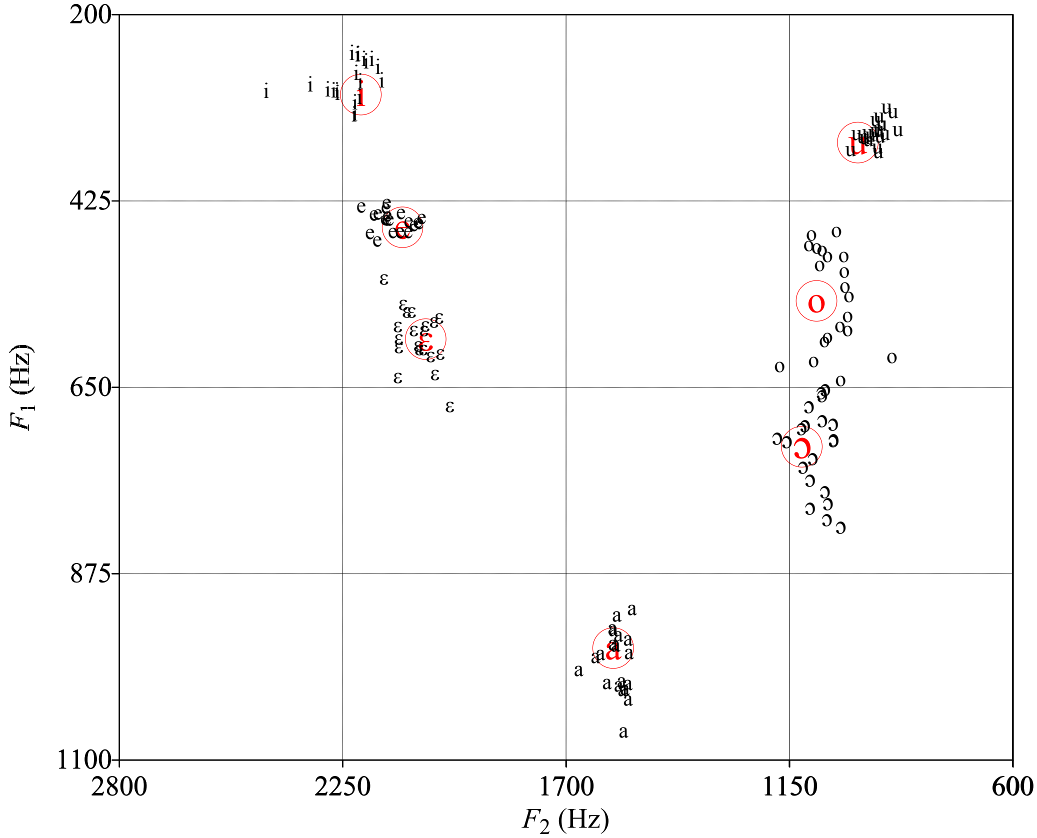


Figure 4.47: F1 vs. F2 vowel formant chart for Londo speaker 5, female (5F-H)

The F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction of [ATR] with both Gender and Vowel Group is not significant [$F(1,381)=1.59$], but [ATR] does interact significantly with Vowel Group [$F(1,381)=7.38$ $p=0.007$] and with Gender [$F(1,381)=550.15$ $p=0.000$] in the two-way interactions. The main effect of [ATR] is also significant [$F(1,381)=974.58$ p=0.000]. These results suggest that there are differences in F1 means within the vowel pairs but that they may not be consistent across vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for two male speakers [1M-CE $F(1,71)=110.52$ and 3M-I $F(1,74)=15.9$; $p=0.000$] but not for the rest [2M-W $F(1,72)=.032$; 4F-M $F(1,76)=1.33$; 5F-H $F(1,76)=4.9$]. The main effect of [ATR], however, is significant for all five speakers [1M-CE $F(1,71)=1483.09$; 2M-W $F(1,72)=572.63$; 3M-I $F(1,74)=910$; 4F-M $F(1,76)=489.41$; 5F-H $F(1,76)=281.19$]. In all cases, $p=0.000$. [+ATR] vowels have significantly lower F1 means than their [-ATR] counterparts. These results confirm that F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, but that the effect is not consistent across vowel groups for some speakers but that it is largely consistent within gender.

To further investigate the Londo vowel system, the F1 values of all the vowels of each Londo speaker were submitted to a one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.29, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.29: Londo F1 Mean Values by Vowel Group for Each Speaker

Vowel Group	Vowel Quality	Pooled Data	1M-CE	2M-W	3M-I	4F-M	5F-H
i	i [+ATR]	284	273	274	312	266	297
e	e [+ATR]	382	346	345	341	420	457
	ɛ [-ATR]	518	458	528	444	557	592
ɑ	ɑ [-ATR]	750	614	725	666	780	965
o	o [+ATR]	417	352	369	360	445	546
	ɔ [-ATR]	576	542	555	494	568	722
u	u [+ATR]	324	300	334	336	305	355

The main effect of Vowel Quality is significant for each Londo speaker [Pooled $F(6,677) = 487.11$; 1M-CE $F(6,133) = 992.7$; 2M-W $F(6,119) = 586.9$; 3M-I $F(6,131) = 836.9$; 4F-M $F(6,127) = 1186.2$; 5F-H $F(6,133) = 824.1$]. In each case, p=0.000. Londo presents a picture similar to that of Mbonge where F1 means are significant for all vowels, whether [ATR] harmony pairs [e]/[ɛ], [o]/[ɔ] or cross-height pairs [i]/[e], [u]/[o]. The partial overlap of cross-height front vowels [i]/e] and back vowels [u]/[o] of speaker 3M-I is superficial, as the overlap of the back vowel pair for speaker 2M-W.

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). Unlike the results for F1, the three-way interaction of [ATR] with Gender and Vowel Group is significant [$F(1,381)=26.83$ p=0.000]. The main effect of [ATR], however is not significant [$F(1,381)=.735$], suggesting that if there are differences in F2 means within the vowel pairs they are not consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for four of the five speakers [1M-CE $F(1,71)=11.11$; 2M-W $F(1,72)=227.36$; 3M-I $F(1,74)=340.06$; 5F-H $F(1,76)=23.13$]. In each case, $p \leq 0.001$. [ATR] does not interact significantly with Vowel Group for one of the females [4F-M $F(1,76)=.736$]. As in the pooled model, the main effect of [ATR] is not significant for any of the speakers, [1M-CE $F(1,71)=5.87$; 2M-W $F(1,72)=.824$; 3M-I $F(1,74)=6.18$; 4F-M $F(1,76)=.372$; 5F-H $F(1,76)=1.15$]. Again, these results suggest that if there are any significant differences in F2 between vowel pairs, they are not consistent across vowel groups.

For a clearer picture of the Londo vowel system, the F2 values of all speakers and for each Londo speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.30, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

As with F1, the main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled $F(6,677) = 505.15$; 1M-CE $F(6,136) = 76.8$; 2M-W $F(6,136) = 1193.1$; 3M-I $F(6,131) = 2191.7$; 4F-M $F(6,127) = 521.4$; 5F-H $F(6,133) = 3108.5$]. In each case, $p=0.000$. But as suggested in the univariate ANOVA and predicted from the scatterplots where considerable overlap of F2 values occurs among the back vowels, F2 is an unreliable predictor of [ATR]. F2 fails to distinguish harmony pairs [o]/[ɔ] for three speakers (1M-CE, 4F-M, 5F-H) and harmony pairs [e]/[ɛ] for 4F-

M. In addition, for four of the five speakers F2 means fail to distinguish one or more cross-height vowel pairs.

Table 4.30: Londo F2 Means by vowel pair for each speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-CE	2M-W	3M-I	4F-M	5F-H
i	i [+ATR]	1996[1]	1764[1]	1921	1844	2422	2205
e	e [+ATR]	1920[1]	1829[1]	1854	1718	2104	2102
	ɛ [-ATR]	1801	1608	1657	1573	2098	2045
ɑ	ɑ [-ATR]	1478	1554	1247	1377	1631	1583
o	o [+ATR]	1014[2]	1146[2]	853	808[1]	1129[1]	1119
	ɔ [-ATR]	1109	1181[2]	1075[1]	1001	1168	1083
u	u [+ATR]	1041[2,]	1241[2]	1056[1]	816[1]	1058[1]	982

4.2.11 Tuwuli

The F1 vs. F2 formant plots for the five Tuwuli speakers of this study are found in Figures 4.48-4.52. Tuwuli has the same vowel inventory as many of the seven-vowel systems seen thus far: /i e ɛ ɑ ɔ o u/ with [+ATR] mid vowels. Unlike the Edekiri and Bantu A and C languages seen so far with this inventory, Tuwuli has been reported to have [+ATR] harmony which spreads from both mid and high vowels. No known surface variants occur. See §2.1.3 for further detail and an alternative analysis based on [-ATR] harmony.

As seen in other seven-vowel languages in this study, there is a clear distinction in F1 between [+ATR] and [-ATR] mid vowels across speakers. In addition, there is also no apparent overlap for F1 between [-ATR] mid vowels and the low vowel for four of the five speakers. The only notable exception is speaker 4F-F. The cross-height [+ATR] vowels, [i]/[e] and [u]/[o] present a different picture, with partial overlap at the edges of the spreads of these vowel pairs among male speakers. This overlap is most noticeable among the back pairs, but the front pair of speaker 3M-A also overlap. There is also an apparent centralization (higher F2 values) of some of the [u] tokens for all speakers. In every case, the more centralized tokens originate from the word *kútû* 'soup' in which the target vowel follows a voiceless alveolar plosive.

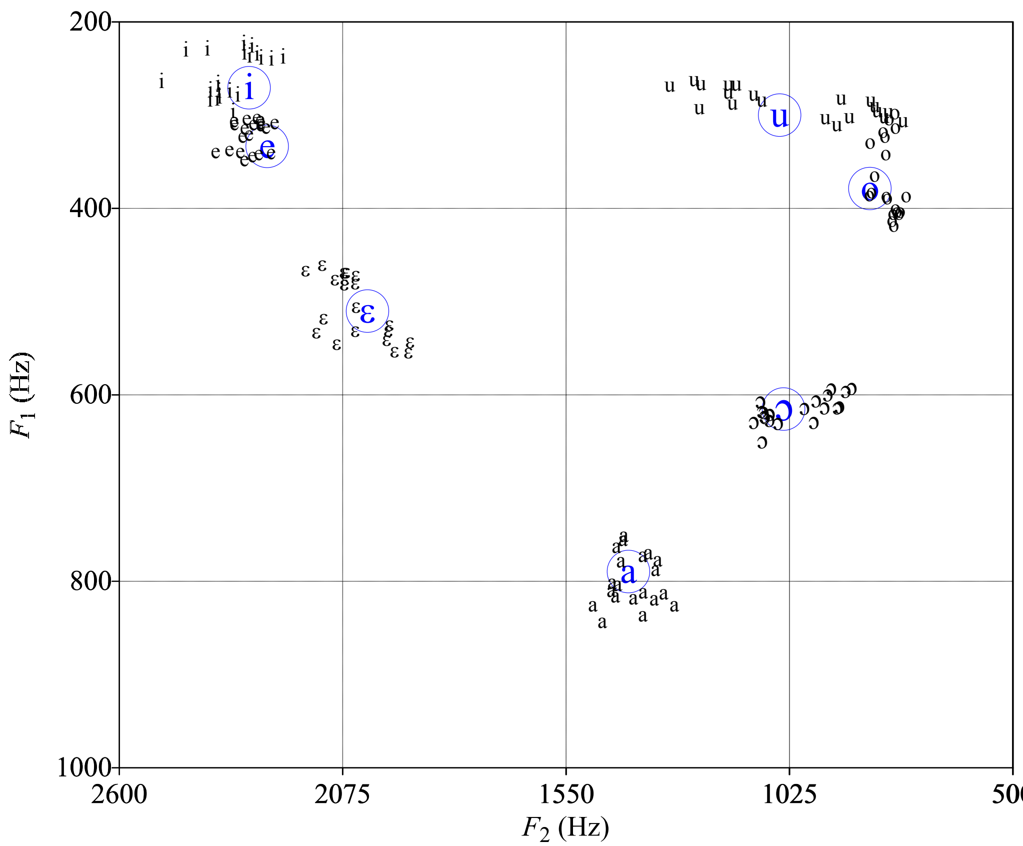


Figure 4.48: F1 vs. F2 vowel formant chart for Tuwuli speaker 1, male (J)

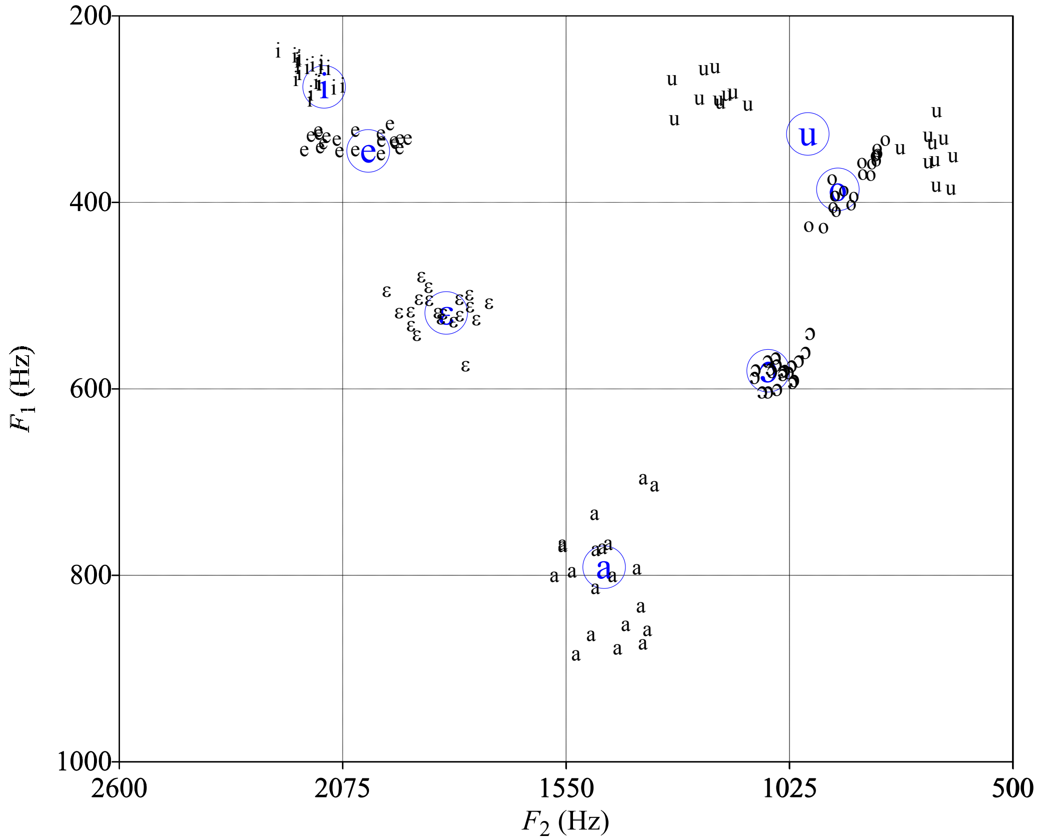


Figure 4.49: F1 vs. F2 vowel formant chart for Tuwuli speaker 2, male (An)

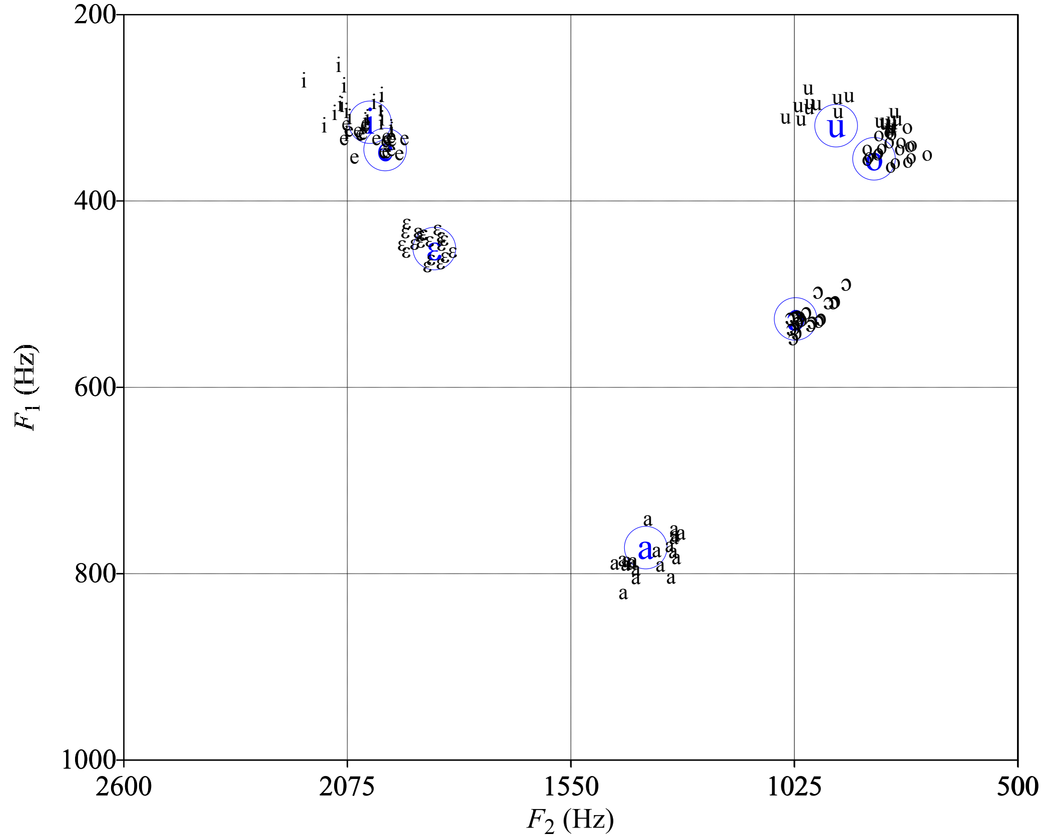


Figure 4.50: F1 vs. F2 vowel formant chart for Tuwuli speaker 3, male (A)

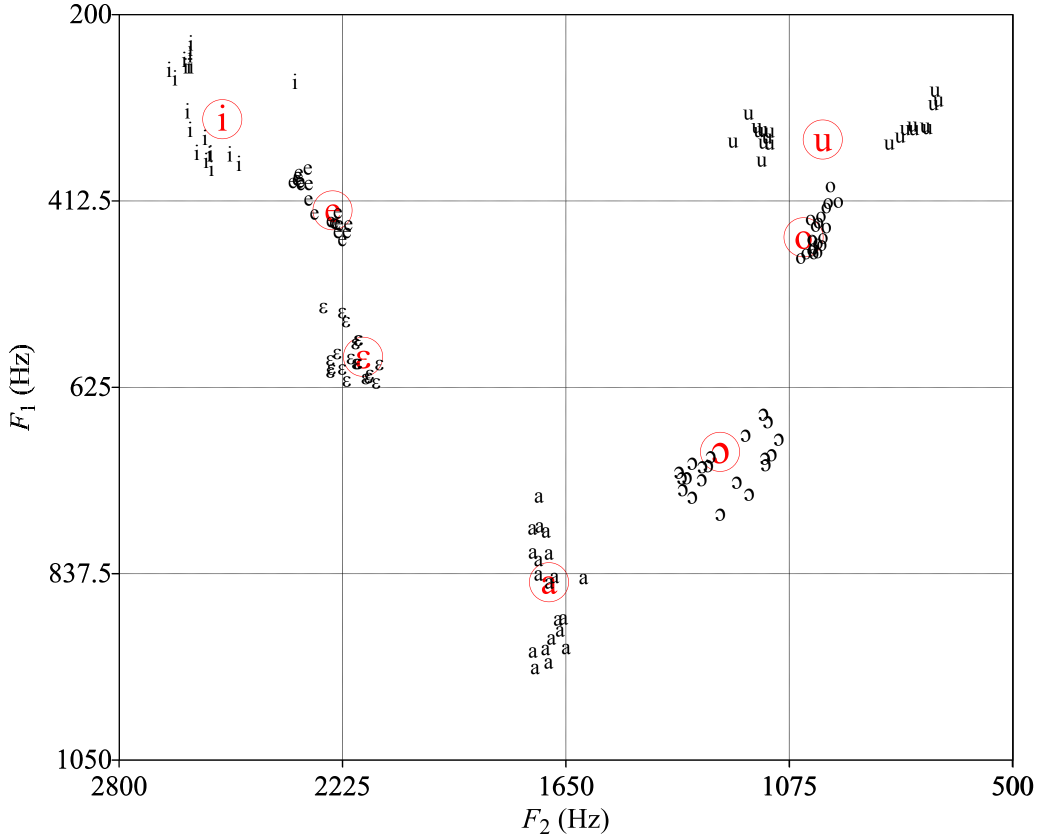


Figure 4.51: F1 vs. F2 vowel formant chart for Tuwuli speaker 4, female (F)

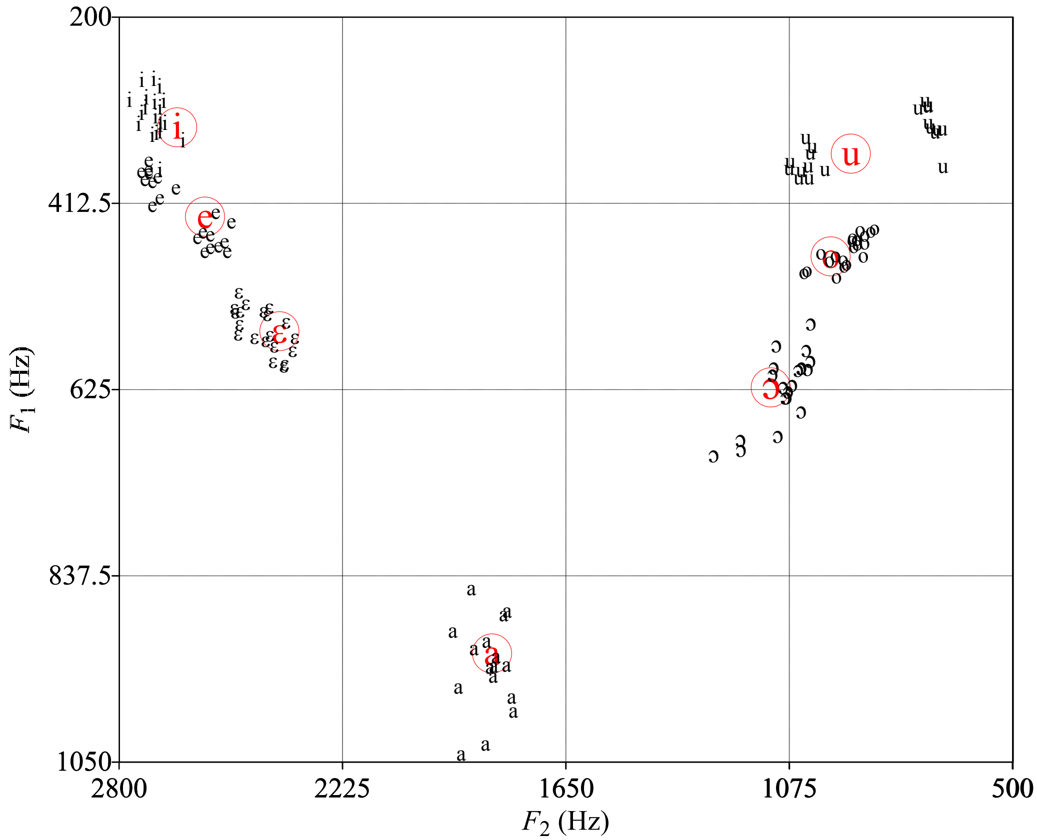


Figure 4.52: F1 vs. F2 vowel formant chart for Tuwuli speaker 5, female (T)

The F1 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] does not interact significantly in the 3 factor analysis with Gender and Vowel Group [$F(1,392)=.149$]. [ATR], however, does interact significantly with Vowel Group [$F(1,392)=55.94$ $p=0.000$]; and the main effect of [ATR] is also significant [$F(1,392)=1634.3$ $p=0.000$]. [+ATR] vowels have significantly lower F1 means than their [-ATR] counterparts. These results suggest that there are differences in F1 means within the vowel pairs and that they are likely to be consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for three of the five speakers [1M-J $F(1,76)=24.18$; 3M-A $F(1,76)=151.71$; 4F-F $F(1,76)=63.15$]. In all cases, $p=0.000$. The main effect of [ATR], however, is significant for all five speakers [1M-J $F(6,133) = 1162.7$; 2M-An $F(6,133) = 791.9$; 3M-A $F(6,131) = 2785.5$; 4F-F $F(6,133) = 634.3$; 5F-T $F(6,129) = 716.7$], ($p=0.000$). [+ATR] vowels have significantly lower F1 means than their [-ATR] counterparts. These results suggest that F1 mean values of [+ATR] vowels differ significantly from their [-ATR] counterparts, and that the effect is mostly consistent across vowel groups for some of the speakers.

To further investigate the Tuwuli vowel system, the F1 values of all the vowels of each Tuwuli speaker were submitted to a one-way ANOVA with F1 as the dependent variable and vowel quality as the independent factor. This model was run for all speakers as well as for each speaker (significance level set to 0.01 for five speakers). The mean F1 values are summarized in Table 4.31, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

Table 4.31: Tuwuli F1 Mean Values by Vowel Group for Each Speaker

Vowel Group	Vowel Quality	Pooled Data	1M-J	2M-An	3M-A	4F-F	5F-T
i	i [+ATR]	302	271	276	316	319	326
e	e [+ATR]	375	334	345	345	423	428
	ɛ [-ATR]	526	510	519	451	590	559
ɑ	ɑ [-ATR]	821	790	791	772	848	926
o	o [+ATR]	409	379	386	355	454	473
	ɔ [-ATR]	611	615	581	527	711	623
u	u [+ATR]	329	300	327	319	343	356

The main effect of Vowel Quality is significant for all speakers as well as for each Tuwuli speaker [Pooled $F(6,689)=1252.53$; 1M-J $F(6,133) = 1162.7$; 2M-An $F(6,133) = 791.9$; 3M-A $F(6,131) = 2785.5$; 4F-F $F(6,133) = 634.3$; 5F-T $F(6,129) = 716.7$], ($p=0.000$). Tuwuli presents a picture similar to that of Ifè where F1 means are significant for all vowels, whether [ATR] harmony pairs [e]/[ɛ], [o]/[ɔ] or cross-height pairs [i]/[e], [u]/[o]. The partial overlap of cross-height front vowels [i]/[e] and back vowels [u]/[o] of speaker 3M-A is superficial, as is the overlap of the back vowel pair for speakers 1M-J and 2M-An.

Next, the F2 values of the [ATR] harmony pairs were submitted to a univariate ANOVA with the same three factors (Vowel Group, [ATR] and Gender). Unlike the results for F1, the three-way interaction of [ATR] with Gender and Vowel Group is significant [$F(1,381)=26.83$ $p=0.000$]. The main effect of [ATR], however, is not significant [$F(1,381)=.735$], suggesting that if there are differences in F2 means within the vowel pairs they are not consistent across gender and vowel group.

Five separate univariate ANOVA were then run, one for each speaker with Vowel Group and [ATR] value as factors (significance level set to 0.01 for five speakers). [ATR] interacts significantly with Vowel Group for four of the five speakers [1M-CE $F(1,71)=11.11$; 2M-W $F(1,72)=227.36$; 3M-I $F(1,74)=340.06$; 5F-H $F(1,76)=23.13$]. In each case, $p \leq 0.001$. [ATR] does not interact significantly with Vowel Group for one of the females [4F-M $F(1,76)=.736$]. As in the combined model, the main effect of [ATR] is not significant for any of the speakers, [1M-CE $F(1,71)=5.87$; 2M-W $F(1,72)=.824$; 3M-I $F(1,74)=6.18$; 4F-M $F(1,76)=.372$; 5F-H $F(1,76)=1.15$]. Again, these results suggest that if there are any significant differences in F2 between vowel pairs, they are not consistent across vowel groups.

For a clearer picture of the Tuwuli vowel system, the F2 values of all speakers and for each Tuwuli speaker were also submitted to a one-way ANOVA with F2 as the dependent variable and vowel quality as the independent factor. These results are summarized in Table 4.32, along with pairwise comparisons as determined by a Tukey Post-Hoc test.

As with F1, the main effect of Vowel Quality is significant for all speakers as well as for each speaker [Pooled $F(6,689) = 1067.52$; 1M-J $F(6,133) = 1095.4$; 2M-An $F(6,133) = 421.2$; 3M-A $F(6,133) = 1982.3$; 4F-F $F(6,133) = 956.6$; 5F-T $F(6,133) = 1896.5$], ($p=0.000$). Unlike many other cases we have seen so far, F2 mean values do distinguish harmony pairs [e]/[ɛ] and [o]/[ɔ] for all speakers but fail to distinguish many of the cross height vowel pairs. That F2 mean values are not significant for high and mid back vowels is not surprising due to the centralization of those tokens of [u] which occur following an alveolar consonant. More interesting is the degree to which F2 mean values fail to distinguish front cross-height pairs [i]/[e] across speakers. F2 mean differences distinguish these vowels for only two of the speakers, 2M-An and 4F-F. This failure cannot be explained by conditioning factors such as surrounding consonants. In three of the four words used for the analysis, the target vowel follows a coronal consonant.

Table 4.32: Tuwuli F2 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-J	2M-An	3M-A	4F-F	5F-T
i	i [+ATR]	2324	2294^{1}	2118	2022^{1}	2534	2651^{1}
e	e [+ATR]	2216	2252^{1}	2014	1986^{1}	2251	2579^{1}
	ɛ [-ATR]	2055	2016	1831	1870	2172	2387
ɑ	ɑ [-ATR]	1542	1403	1460	1374	1694	1840
o	o [+ATR]	918^{1}	835	911^{1}	837	1037^{1}	968^{2}
	ɔ [-ATR]	1104	1038^{2}	1074^{2}	1021	1264	1123
u	u [+ATR]	972^{1}	1047^{2}	$981^{1,2}$	926	988^{1}	916^{2}

4.3 F1 Bandwidth (B1)

This section presents the results of the F1 bandwidth (B1) analysis for each of the eleven languages featured in this study. For each language, the following is presented:

- B1 vs. F1 frequency charts for each speaker,
- the scatter plots of cross-height vowels whose F1 values overlap (where relevant) and
- the results of the ANOVA for Delta B1 ($\Delta B1$), the differential of the observed and predicted values of B1, as well as ANOVA of observed B1 values for vowels overlapping in F1.

The following are presented in bandwidth frequency display:

- the mean of each vowel represented by colored markers and IPA character and
- a dotted line representing the predicted values of B1 for any given F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract.

As above, the level of statistical significance has been set at $p \leq 0.05$ (unless otherwise indicated).

4.3.1 Foodo

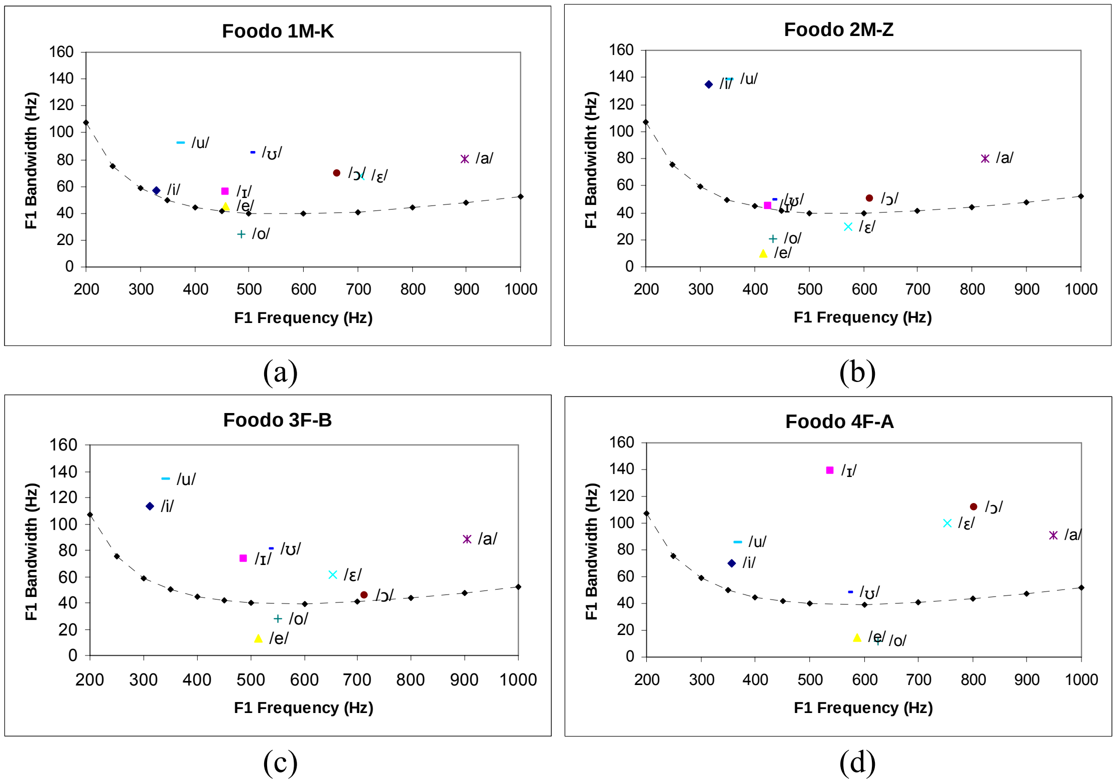


Figure 4.53: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Foodo speakers (a) 1M-K, (b) 2M-Z, (c) 3F-B and (d) 4F-A

Figure 4.53 (a)-(d) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for each vowel for the four Foodo speakers. There are several generalizations which may be drawn from the examination of these four plots. One is the tendency for [+ATR] high vowels to have B1 means well above the predicted values. This effect is most noticeable for speakers 2M-Z and 3F-B, whose vowels have B1 means 50 Hz to 80 Hz, (or more), higher than the predicted values. This effect is present – though less noticeable – for speaker 4F-A, whose [+ATR] high vowels are 27-

37 Hz above predicted values, as it is for the back high [+ATR] vowel of speaker 1M-K, whose B1 mean for this vowel is 45 Hz higher than the predicted value.

Another tendency noticeable in Figure 4.53 is for [+ATR] mid vowels to have B1 mean values ranging 10-30 Hz below predicted values. The only exception is found in figure (a) for speaker 1M-K, whose /e/ has a mean B1 value just slightly above the predicted value (3.75 Hz.) On the other hand, the [-ATR] high vowels, which are known to overlap with the [+ATR] mid vowels for F1 frequency, have B1 means either near or above their predicted B1 values. This is seen most noticeably in the plots of speakers 2M-Z and 3F-B. It is also true for the other two speakers who have at least one vowel with B1 means well above the predicted value.

The major difference among speakers lies with [-ATR] mid vowels. Speakers 2M-Z and 3F-B have [-ATR] mid vowels whose B1 means are within 20 Hz of predicted values while Speakers 1M-K and 4F-A have [-ATR] mid vowels with B1 means 30-65 Hz above predicted values. All speakers have similar B1 means for the low vowel: 32-41 Hz above predicted values.

In order to evaluate the displacement of the observed B1 values from those predicted by the Fant 1972 formula for modeling the effects of various losses within the vocal tract, the differentials of observed B1 and predicted B1 (i.e. ΔB1) for the [ATR] harmony vowel pairs for the Foodo speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.1: Vowel Group (/i ɪ/, /e ɛ/, /o ɔ/ and /u ʊ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] interacts significantly with both Gender and Vowel Group [$F(3,624)=4.09$, $p=0.007$]. The main effect of [ATR] is also significant [$F(1,624)=26.95$, $p=0.000$], with [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of ΔB1 includes four separate ANOVA, one for each speaker (significance level set to 0.0125 for four comparisons), with [ATR] and Vowel Group as factors (Table 4.33). [ATR] interacts significantly with Vowel Group in all four cases, and the main effect of [ATR] is significant in three of four cases (1M-K, 2M-Z, 4F-A). However, only speakers 1M-K and 4F-A have [-ATR] vowels with greater ΔB1 means than their [+ATR] counterparts.

Table 4.33: Univariate ANOVA Results for ΔB1 in Foodo

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, $p=0.000$; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-K	$F(3,152)=6.67$	$F(1,152)=24.16$	√
2M-Z	$F(3,152)=65.08$	$F(1,152)=43.77$	
3F-B	$F(3,152)=12.13$	$F(1,152)=0.465$	
4F-A	$F(3,152)=52.26$	$F(1,152)=204.79$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data.[48] The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(8,711) = 46.51$; 1M-K $F(8,171) = 15.18$; 2M-Z $F(8,171) = 51.35$; 3F-B $F(8,171) = 19.84$; $F(8,171) = 46.21$]. In every case, $p=0.000$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.34.

Table 4.34: Foodo ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different. Yellow highlighting indicates the [-ATR] vowel has a significantly lower mean than its [+ATR] counterpart.

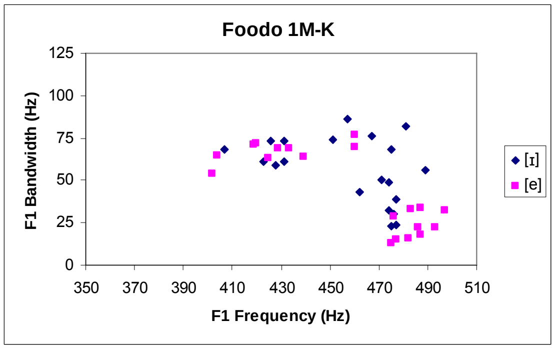
Vowel Group	Vowel Quality	Pooled Data	1M-K	2M-Z	3F-B	4F-A
i	i [+ATR]	40.2	3.8	79.4	56.6	20.8
	ɪ [-ATR]	36.5	14.9[1]	1.7	29.7	99.7
e	e [+ATR]	-20.7	3.8[1]	-34.1	-27.3	-28
	ɛ [-ATR]	23.4	26.4	-10.2	20.7	57
ɑ	ɑ [-ATR]	37.3	32.5	35.2	40.8	40.7
o	o [+ATR]	-19.3	-16	-22.1[1]	-11	-25.1
	ɔ [-ATR]	27.9	29.5	10.6	3.6	67.9
u	u [+ATR]	58.4	45	88.6	63.3	36.8
	ʊ [-ATR]	25.3	44.7	7[1]	41.2	8.1

The results of the one-way ANOVA for Foodo ΔB1 indicate that overall mean differences for high vowel [ATR] pairs are either not significantly different or have [-ATR] vowels with significantly lower ΔB1 means than their [+ATR] counterparts. The only exception is the high front [ATR] pair for speaker 4F-A, in which [-ATR] [ɪ]

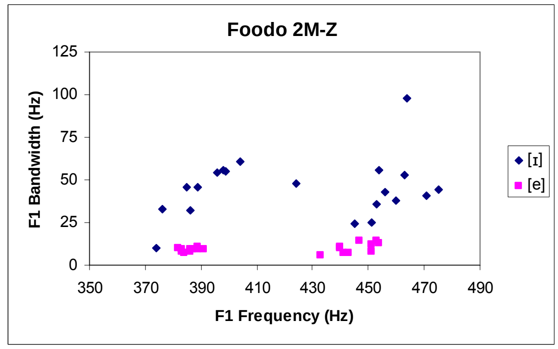
[48] Note that a relatively conservative model was adopted for ΔB1 one-way ANOVA for Foodo and subsequent languages in that all vowels, not just [ATR] pairs, are included in the model. Wherever relevant, results of ANOVA models that target only [ATR] are reported.

has a ΔB1 mean nearly five times greater than [+ATR] [i]. Mid-vowel [ATR] pairs fare better with most [-ATR] vowels having significantly greater ΔB1 means than their [+ATR] counterparts. Three mid-vowel pairs, one each for speakers 1M-K, 2M-Z, 3F-B, show tendencies for the [-ATR] vowel to have a greater ΔB1 mean; these differences are however not statistically significant. Overall, ΔB1 differences are most robust for speaker 4F-A, for whom three of four [ATR] vowel pairs have greater ΔB1 means for [-ATR] vowels than for their [+ATR] counterparts. Note also that there is only one instance where the ΔB1 mean of a [-ATR] vowel is below the predicted value – the [ɛ] of speaker 2M-Z.

In addition to the [ATR] harmony pairs, the one-way ANOVA results also indicate which cross-height vowel pairs do not have statistically significantly different ΔB1 means. In this case, there are two pairs which do not have significant mean differences – [ɪ]/[e] for speaker 1M-K and [ʊ]/[o] for speaker 2M-Z. Since F1 means for cross-height vowels tend not to be significantly different in Foodo, their B1 means are considered more closely.



(a)



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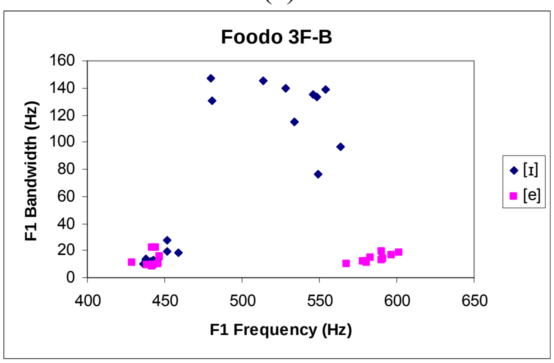

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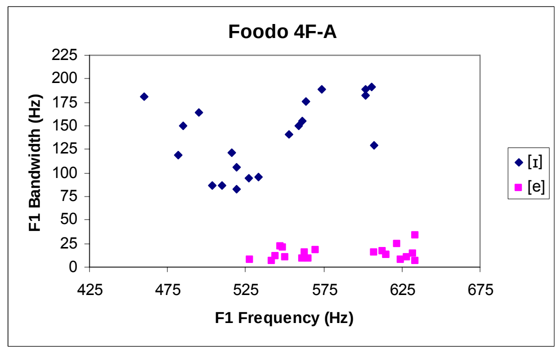


(d)

Figure 4.54: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pairs [ɪ]/[e] Foodo speakers (a) 1M-K, (b) 2M-Z, (c) 3F-B and (d) 4F-A

Figure 4.54 (a)-(d) displays scatterplots comparing F1 vs. B1 for cross height [+ATR] [e] and [-ATR] [ɪ] for each of the Foodo speakers. Recall from §4.2.1 that there was considerable overlap of F1 for Foodo cross-height vowels; the F1 mean differences for the front pair for speakers 1-3 proved not to be statistically significant. The B1 scatterplots for these speakers paint a somewhat different picture, however (figures (a)-(c), respectively). For speaker 1M-K, there is considerable overlap of the B1 values, but not for speaker 2M-Z, where the B1 values for the [-ATR] vowel are all higher than for the [+ATR] vowel. Speaker 3F-B has mixed results. Some tokens of the [-ATR] vowel overlap with the B1 values of the [+ATR] vowel; other tokens of the [-ATR] vowel have B1 values well above those of the [+ATR] vowel. Note that the tokens of the [-ATR] vowel which overlap in F1 and B1 frequencies with the [+ATR] vowel are from the word *tìlì* ‘to brand’ but those which have B1 frequencies much higher than the [+ATR] vowel come from the word *díísá* ‘to ask’. Finally, while the F1 mean differences of [ɪ] vs. [e] for speaker 4F-Z proved to be statistically significant, the amount of overlap of F1 for these two vowels in the 525-625 Hz range is nonetheless quite prominent in figure (d). The B1 values in this range, however, are completely separated with the [-ATR] values much higher than the [+ATR] values.

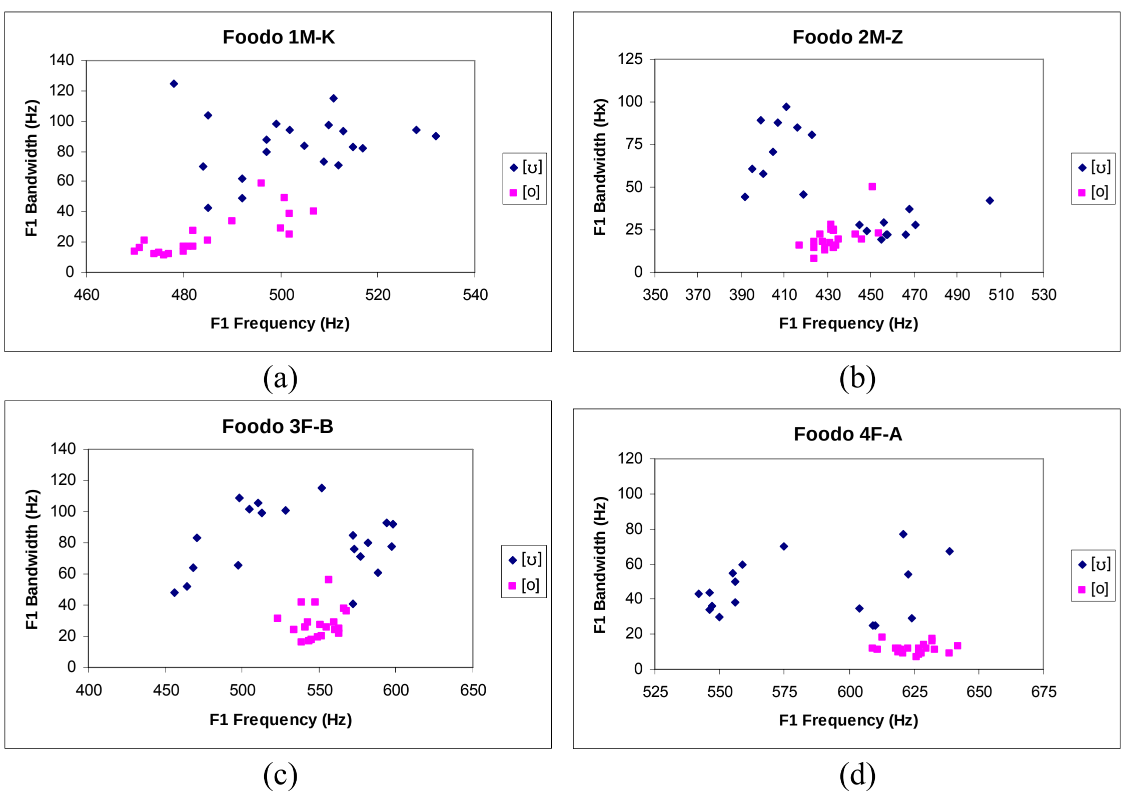


Figure 4.55: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pairs [ʊ]/[o] for Foodo speakers (a) 1M-K, (b) 2M-Z, (c) 3F-B and (d) 4F-A.

Figure 4.55 (a)-(d) are the scatterplots comparing F1 vs. B1 for the back cross height pair, [+ATR] [o] and [-ATR] [ʊ] for each of the Foodo speakers. Again, from §4.2.1 we know that the cross-height pair for speaker 4F-A have statistically significant F1 means. For those tokens which do overlap for B1 in her scatterplot, figure (d), the [-ATR] values are higher than the [+ATR] values. For the rest of the speakers, there is a tendency again for the B1 values of the [-ATR] vowel to be higher than for the [+ATR] vowel.

To further investigate the cross-height vowel pairs, the F1 bandwidth (B1) values for all the vowels of the pooled data as well as of each Foodo speaker were submitted to a one-way ANOVA with B1 as the dependent variable and vowel quality as the independent factor. The results for the front and back cross-height vowels are summarized in Table 4.35, along with pairwise comparisons as determined by a Tukey Post-Hoc test (significance level set to 0.0125 for four speakers). The main effect of Vowel Quality is significant (p=0.000) for the pooled data and for each speaker [Pooled $F(8,711)=56.73$; 1M-K $F(8,171) = 15.12$; 2M-Z $F(8,171) = 61$; 3F-B $F(8,171) = 27.77$; 4F-A $F(8,171) = 47.56$].

Table 4.35: Foodo B1 Mean Values for Cross-height Vowels for Each Speaker

Cells with the same degree of shading within columns indicate mean values which are not significant. Superscript numbers indicate vowels of the same phonological height whose B1 means are not significantly different

Vowel Quality	Pooled Data	1M-K	2M-Z	3F-B	4F-A
ɪ [-ATR]	78^{1}	56	45^{1}	70^{1}	139
e [+ATR]	21^{2}	45^{1}	10^{2}	13^{2}	14^{1}
o [+ATR]	21^{2}	24^{1}	20^{2}	28^{2}	12^{1}
ʊ [-ATR]	66^{1}	85	50^{1}	81^{1}	48

For the pooled data in Table 4.35, the B1 means for height 2 vowels, [-ATR] [ɪ ʊ], are significantly different than for those of height 3, [+ATR] [e o], but the cross-height vowel pairs [ɪ e] and [ʊ o] have significantly different B1 means. The same pattern for cross-height pairs is reflected in the results for the two women, 3F-B and 4F-A. The male speakers, however, have one cross-height pair each where the B1 means are not significantly different: the front pair for 1M-K and the back pair for 2M-Z. Note that these are the same two pairs whose ΔB1 means were not statistically significantly different. In addition, Speakers 2M-Z and 3F-B reflect the pooled data for height internal vowels. For speakers 1M-K and 4F-Z, only the [+ATR] vowels have B1 means that are not significantly different.

In sum, setting aside for now the question of the high B1 mean values for [+ATR] high vowels in Foodo, there is a general tendency in Foodo for B1 mean values of [-ATR] vowels to be higher than [+ATR] vowels. This is best reflected in the

[+ATR] mid vowels whose F1 mean values are overall not statistically significant from [-ATR] high vowels. In most cases, the bandwidth means of the [-ATR] high vowel are significantly higher than those of its cross-height [+ATR] mid vowel pair. This tendency is also noted in the ΔB1 results where [-ATR] mid vowels overall have greater ΔB1 means than their [+ATR] counterparts.

4.3.2 Ikposo

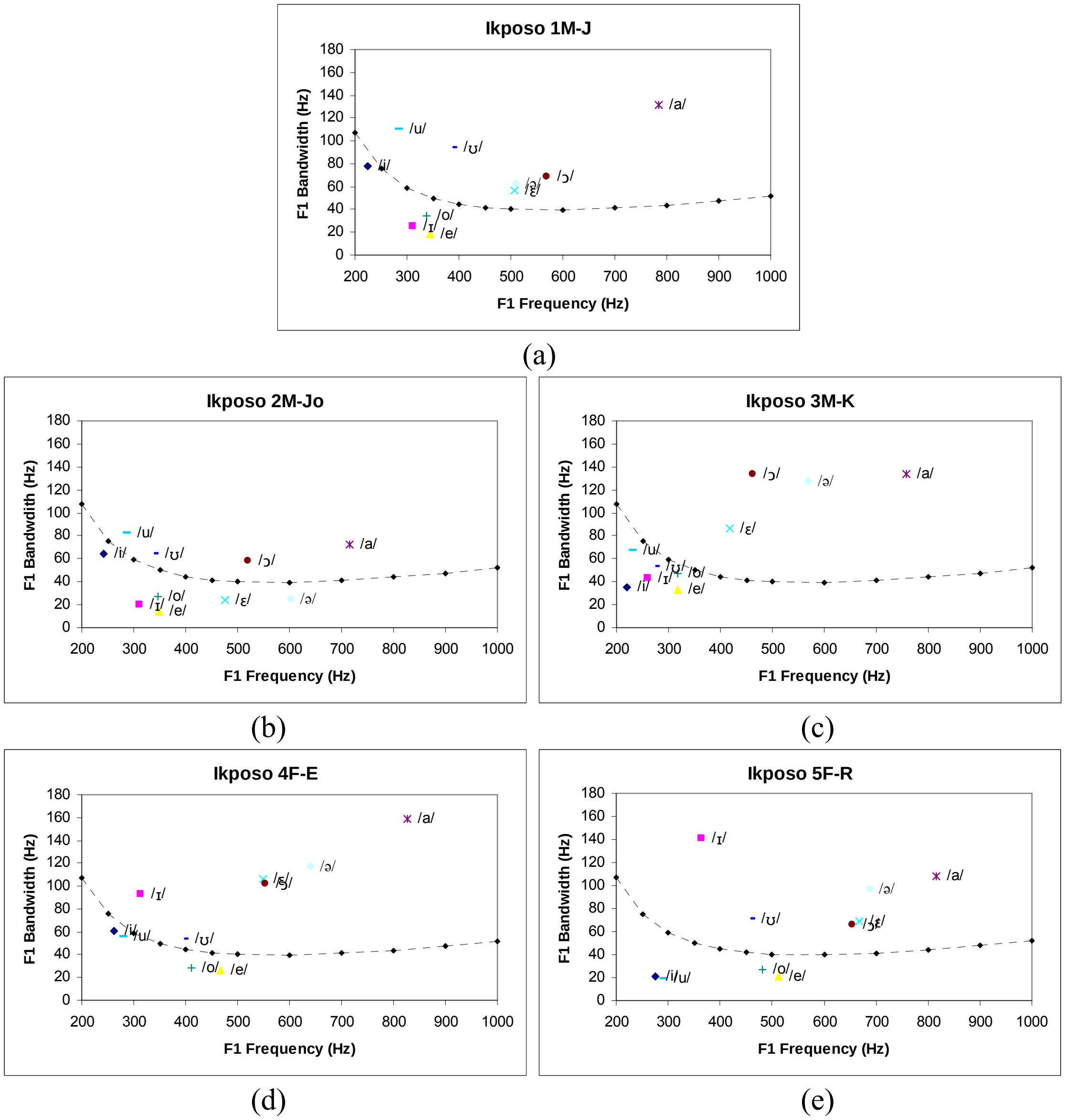


Figure 4.56: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant’s (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Ikposo speakers (a) 1M-J, (b) 2M-Jo, (c) 3M-K, (d) 4F-E and (e) 5F-R

Figure 4.56 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the Ikposo speakers. Recall that Ikposo along with Foodo are the only two languages represented in this study with [+ATR] dominance and an underlying 9(10) vowel system. We have already seen differences in how in the acoustic spread of high and mid vowels between these two languages. The most noticeable difference between Ikposo and Foodo bandwidths occurs in the [+ATR] high vowels: while Foodo tends to have B1 means much higher than the projected values for these vowels, Ikposo tends to have comparatively lower B1 frequencies for these vowels with means either within 20 Hz above (2M-Jo) or more than 40 Hz below than projected values (3M-K, 5F-R). The most noticeable inter-gender difference within Ikposo speakers is the B1 mean of [-ATR] [ɪ]. Ikposo males all present B1 means 25-35 Hz below the predicted means while the females have means 40-90 Hz above the predicted means. A similar pattern was noticed between Foodo male and female speakers; females have overall higher B1 means for [-ATR] high vowels than males. Finally, setting aside for now the behavior of [+ATR] /ə/ (which is not the harmonic counterpart of [-ATR] /a/), there is an overall tendency among Ikposo females for the [-ATR] vowels to have B1 means that are relatively higher than the predicted means than among the males.

The ΔB1 values for the [ATR] harmony vowel pairs for the Ikposo speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.2: Vowel Group (/i ɪ/, /e ɛ/, /o ɔ/ /u ʊ/ and /ə ɑ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] interacts significantly with both Gender and Vowel Group [$F(4,967)=22.47$, $p=0.000$] and that the main effect of

[ATR] is also significant [$F(1,967)=417.57$, $p=0.000$], [-ATR] vowels having greater ΔB1 means than [+ATR] vowels. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.36). [ATR] interacts significantly with Vowel Group in all five cases, and the main effect of [ATR] is significant for all speakers, [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.36: Univariate ANOVA Results for ΔB1 in Ikposo

Mean differences are significant at $p \leq 0.001$; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-J	$F(4,189)=28.17$	$F(1,189)=91.91$	√
2M-Jo	$F(4,189)=48.2$	$F(1,189)=70.57$	√
3M-K	$F(4,179)=34.55$	$F(1,179)=155.31$	√
4F-E	$F(4,190)=11.81$	$F(1,190)=211.71$	√
5F-R	$F(4,190)=27.95$	$F(1,190)=215.45$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(9,977) = 84.59$; 1M-J $F(9,189) = 67.98$; 2M-Jo $F(9,189) = 67.96$; 3M-K $F(9,179) = 123.45$; 4F-E $F(9,190) = 68311$; 5F-

R $F(9,190) = 50.35$]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.37.

Table 4.37: Ikposo ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different. Yellow highlighting indicates the [-ATR] vowel has a significantly lower mean than its [+ATR] counterpart.

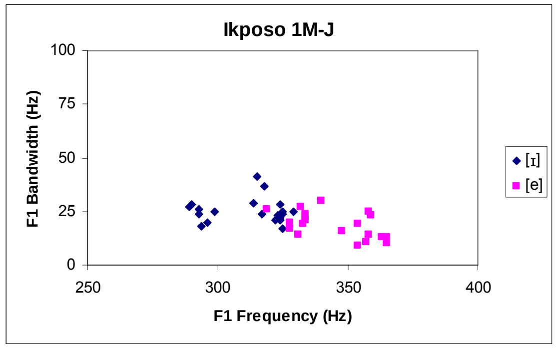
Vowel Group	Vowel Quality	Pooled Data	1M-J	2M-Jo	3M-K	4F-E	5F-R
i	i [+ATR]	-28.1	-12.3	-15.4	-57.2	-10.7	-44.9
	ɪ [-ATR]	5.9	-31.2[1]	-37.3[1]	-30.2[1]	33.8	92.5
e	e [+ATR]	-25	-32.3[1]	-36.9[1]	-22.1[1]	-14.3	-19
	ɛ [-ATR]	27.5	16.2	-16.2	42.7	66.9	28.2
ɑ	ə [+ATR]	46	21.5	-14	88.3	77.1	56.2
	ɑ [-ATR]	75.9	87.7	31.3	90.9	114	63.1
o	o [+ATR]	-15.7	-17.4	-23.6	-8.2[1]	-15.7	-13.4
	ɔ [-ATR]	45.7	29.5	18.5	91.9	62.4	26
u	u [+ATR]	-.92	46.7	19.9	-19.1	-9.2	-42.9
	ʊ [-ATR]	17.4	48.4	13.5	-13.4[1]	8.7	29.6

The results of the one-way ANOVA for ΔB1 in Ikposo are more robust than in Foodo, faring best among mid vowels. [-ATR] mid vowels consistently have statistically significantly greater ΔB1 means than their [+ATR] counterparts. In addition, with the exception of speaker 2M-Jo's [ɛ], all [-ATR] mid vowels have ΔB1 means greater than the predicted value and all [+ATR] mid vowels have ΔB1 means lower than the predicted value. Three of five speakers also have significant differences in the ΔB1 means for low vowels with [-ATR] [ɑ] having a higher ΔB1 mean than

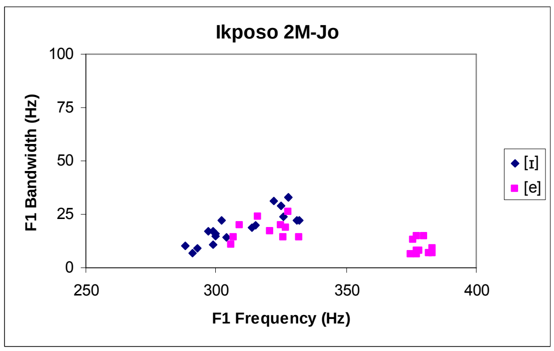
[+ATR] [ə]. High vowels, as in Foodo, fare the worse, especially among back vowels where only speaker 5F-R's [u] and [ʊ] have statistically significantly different ΔB1 means. Note also that although four of five speakers have front high vowels with statistically significantly different ΔB1 means, the direction of the displacement for this vowel pair in the case of 2M-Jo indicates that [-ATR] [ɪ] has a narrower bandwidth than [+ATR] [i] for this speaker.

In addition to the [ATR] harmony pairs, the one-way ANOVA results also indicate which cross-height vowel pairs do not have statistically significantly different ΔB1 means. ΔB1 means for front cross-height pair [+ATR] [e] and [-ATR] [ɪ] are not statistically significantly different for any of the male speakers. ΔB1 means are also not significantly different for cross-height pair [+ATR] [o] and [-ATR] [ʊ] in the case of 3M-K. In all other cases where cross-height ΔB1 means are statistically significantly different [-ATR] vowels have a positive displacement while [+ATR] vowels have a negative displacement from predicted values.

Overall, there is a strong tendency in Ikposo for ΔB1 mean values of [-ATR] vowels to be greater than [+ATR] vowels, and for the [-ATR] vowels to have a positive displacement of ΔB1 but for [+ATR] vowels to have a negative displacement of ΔB1 relative to predicted values. The observed B1 values for Ikposo are further considered below.



(a)



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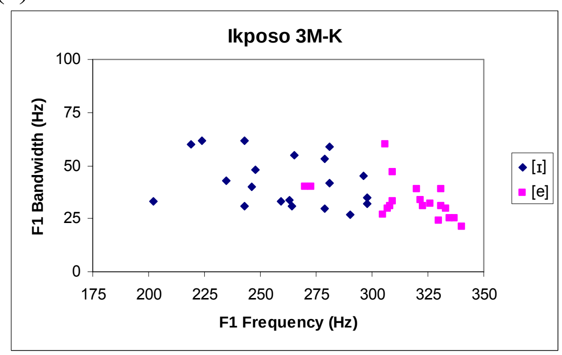

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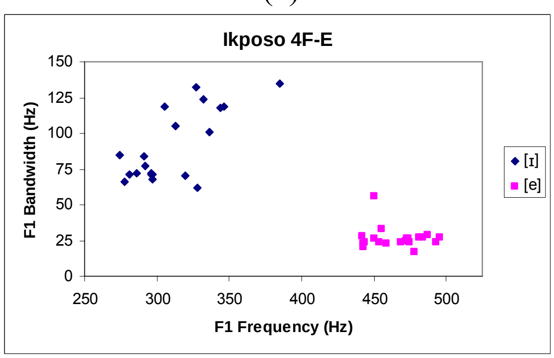

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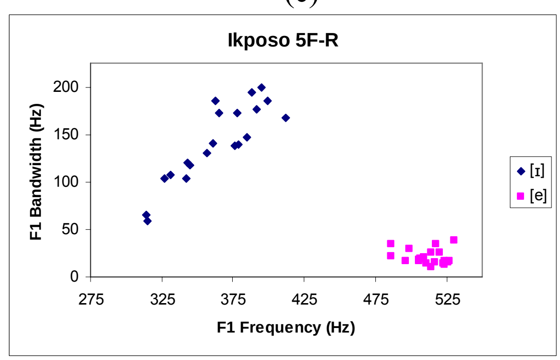
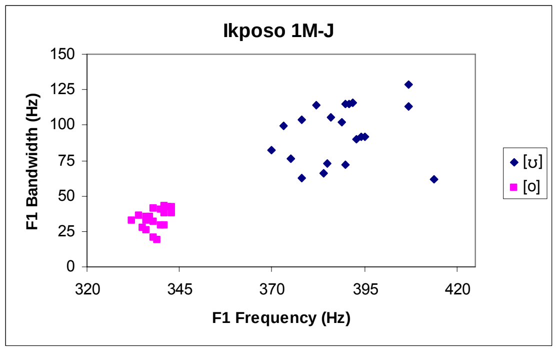


(e)

Figure 4.57: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ɪ]/[e] for Ikposo speakers (a) 1M-J, (b) 2M-Jo, (c) 3M-K, (d) 4F-E and (e) 5F-R.

Figure 4.57 (a)-(e) displays scatterplots comparing F1 vs. B1 for cross height [+ATR] [e] and [-ATR] [ɪ] for each of the Ikposo speakers. Recall that there is less of a tendency for these vowels to overlap for F1 in Ikposo than in Foodo, suggesting that F1 does a better job of distinguishing between each member of the cross-height pair. The overlap at the edges of the F1 ranges is noticeable only among the male speakers; F1 mean values for these vowels were shown in §4.2.2 to be significantly different. For bandwidth, however, there is a mixed picture: figures (a)-(c) show considerable overlap of bandwidth values for the two vowels among male speakers while (d)-(e) show less overlap of bandwidth values among female speakers.



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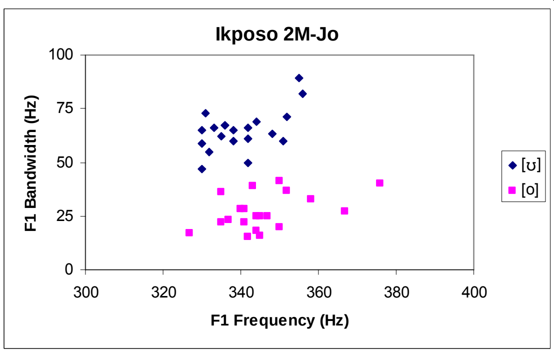
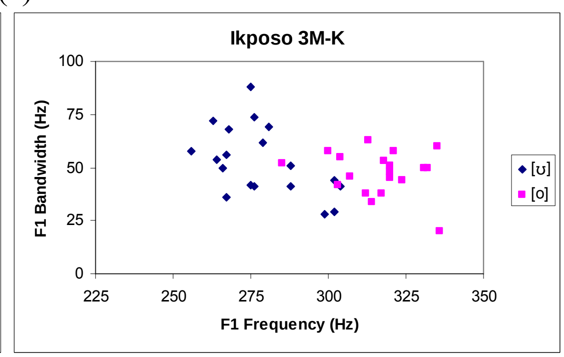
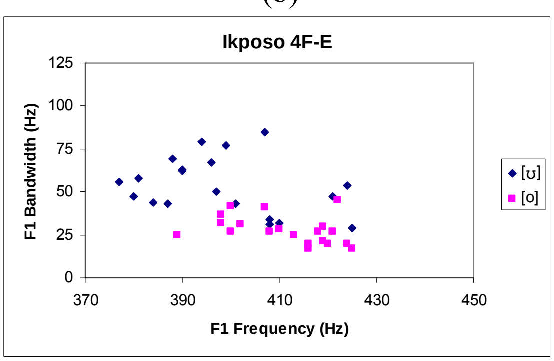
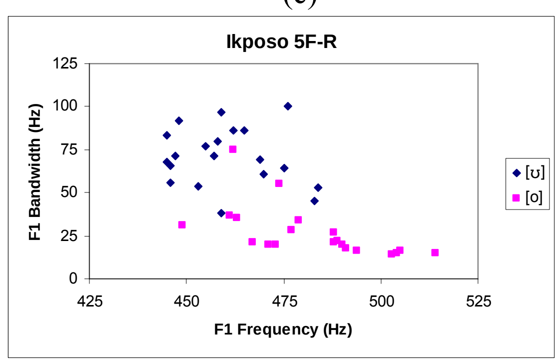




(b) (c)





(d) (e)

Figure 4.58: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ʊ]/[o] for Ikposo speakers (a) 1M-J, (b) 2M-Jo, (c) 3M-K, (d) 4F-E and (e) 5F-R.

Figure 4.58 (a)-(e) are the scatterplots comparing F1 vs. B1 for the back cross height pair, [+ATR] [o] and [-ATR] [ʊ] for each of the Ikposo speakers. From §4.2.2 we know that the mean values of these two vowels are not significantly different for speakers 2M-Jo, 4F-E and 5F-R. The bandwidth scatterplots for these speakers, figures (b), (d) and (e) respectively, reveal an overall tendency for the [-ATR] vowel of this pair to have higher bandwidths than the [+ATR] vowel.

In a further investigation of the cross-height vowel pairs, the F1 bandwidth (B1) values for all the vowels of the pooled data as well as of each speaker were submitted to a one-way ANOVA with B1 as the dependent variable and vowel quality as the independent factor. The results for the front and back cross-height vowels are summarized in Table 4.38, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The main effect of Vowel Quality is significant (p=0.000) for the pooled data and for each speaker [Pooled $F(9,977)=58.3$; 1M-J $F(9,189) = 67$; 2M-Jo $F(9,189) = 68.81$; 3M-K $F(9,179) = 65.79$; 4F-E $F(9,190) = 58.89$; 5F-R $F(9,190) = 43.06$].

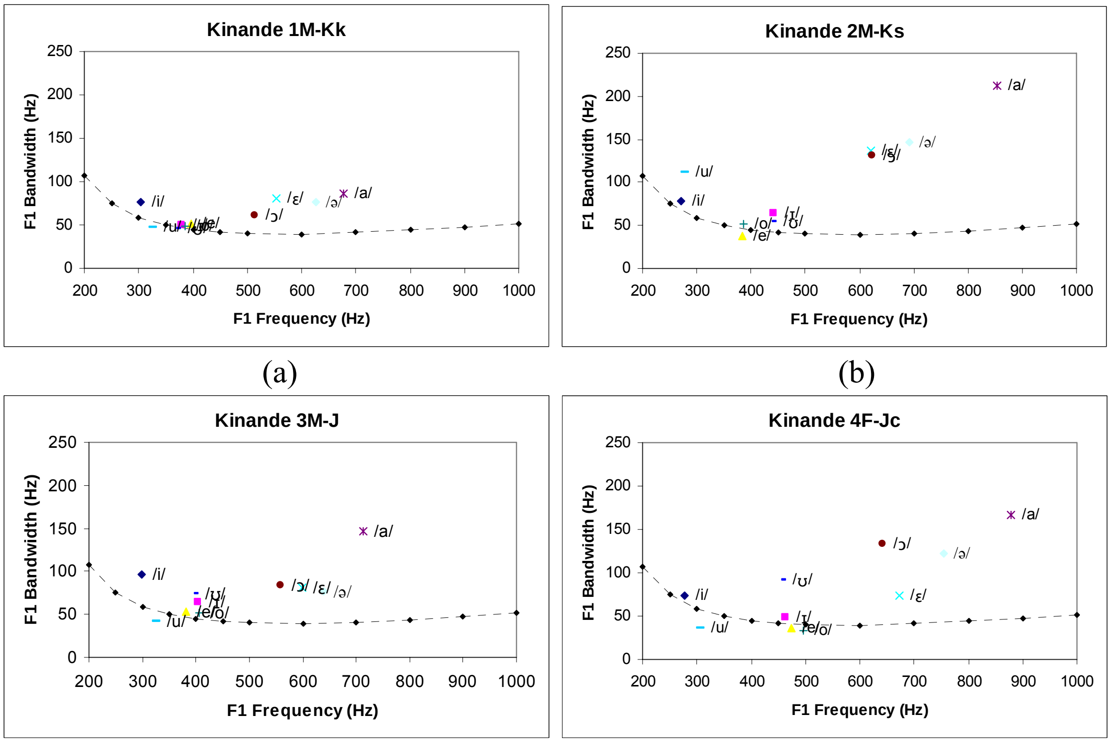
Table 4.38: Ikposo B1 Mean Values for Cross-height Vowels for Each Speaker

Cells with the same degree of shading within columns indicate mean values which are not significantly different. Superscript numbers indicate vowels of the same phonological height whose B1 means are not significantly different

Vowel Quality	Pooled Data	1M-J	2M-Jo	3M-K	4F-E	5F-R
ɪ [-ATR]	64^1	25	20	43^1	91	141
e [+ATR]	23^2	18^1	14^1	34^1	27^1	21^1
o [+ATR]	33^2	34^1	27^1	47^1	28^1	27^1
ʊ [-ATR]	67^1	94	65	54^1	53	71

For the pooled data in Table 4.38, the B1 means for height 2 vowels, [-ATR] [ɪ ʊ], are significantly different than for those of height 3, [+ATR] [e o]. For each of the speakers, the mean B1 values of each of the height 2 vowels are also not significantly different. As expected, the mean B1 values for front cross-height vowels [ɪ] and [e] are not significantly different for the three male speakers, but are so for the females. Also as anticipated, the mean B1 values of back cross-height vowels [ʊ] and [o] are not significantly different for 3M-K. With the exception the back cross-height vowels of speaker 4F-E, these results parallel those of ΔB1 for the cross-height vowels. Note however, that when speaker 4F-E's cross-height vowels are submitted to a separate ANOVA, both pairs have significantly different B1 mean values: $F(1,76)=71.07$, $p=0.000$.

4.3.3 Kinande



(a) (b) (c) (d)

Figure 4.59: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Kinande speakers (a) 1M-Kk, (b) 2M-Ks, (c) 3M-J, and (d) 4F-Jc

Figure 4.59 (a)-(d) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the four Kinande speakers. Recall that the vowel system of Kinande has seven contrastive vowels but ten surface forms. The plots in Figure 4.59 present a picture more like those of Ikposo than Foodo. The bandwidths for most [+ATR] high and mid vowels are within 17 Hz of the predicted B1 values. In addition, with the exception of the [-ATR] /ʊ/ vowel for 3M-J and 4F-Jc, the B1 means of [-ATR] high vowels are also within 20 Hz of the predicted values. There is no consistent pattern for the B1 mean values of [-ATR] mid vowels or for the low vowels, other than that [+ATR] [ə] tends to pattern with [-ATR] mid vowels. This was also the case for the Ikposo data. The [-ATR] mid vowels of speakers 1M-Kk and 3M-J have B1 means within 40 Hz of predicted values while the means of speakers 2M-Ks and 4F-Jc are more than twice that. With the exception of 1M-Kk, the B1 mean of /a/ tends to be greater than 150 Hz, or more than 100 Hz greater than the predicted B1 value.

The ΔB1 values for the [ATR] harmony vowel pairs for the Kinande speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.3: Vowel Group (/i ɪ/, [e ɛ], [o ɔ] /u ʊ/ and [ə ɑ]), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] interacts significantly with both Gender and Vowel Group [$F(4,810)=12.75$, $p=0.000$] and that the main effect of [ATR] is also significant [$F(1,810)=284.95$, $p=0.000$], [-ATR] vowels having greater ΔB1 means than [+ATR] vowels. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of ΔB1 includes four separate ANOVA, one for each speaker (significance level set to 0.0125 for four comparisons), with [ATR] and Vowel Group as factors (Table 4.39). [ATR] interacts significantly with Vowel Group in all four cases, and the main effect of [ATR] is significant for all speakers, [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.39: Univariate ANOVA Results for ΔB1 in Kinande

Mean differences are significant at p = 0.000; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-Kk	$F(4,190)=23.66$	$F(1,189)=35.42$	√
2M-Ks	$F(4,200)=48.14$	$F(1,200)=160.93$	√
3M-J	$F(4,200)=27.24$	$F(1,189)=134.42$	√
4F-Jc	$F(4,200)=38.82$	$F(1,200)=322.76$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(9,820)$ = 109.53; 1M-Kk $F(9,190)$ = 47.1; 2M-Ks $F(9,200)$ = 99.68; 3M-K $F(9,200)$ = 48.98; 4F-Jc $F(9,200)$ = 116.69]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.40.

Table 4.40: Kinande ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different. Yellow highlighting indicates the [-ATR] vowel has a significantly lower mean that its [+ATR] counterpart.

Vowel Group	Vowel Quality	Pooled Data	1M-Kk	2M-Ks	3M-J	4F-Jc
i	i [+ATR]	18.2	17.7	10	37.1	8.1
	ɪ [-ATR]	13.2[1]	3.4[1]	22.3	19.2[1]	7.8[1]
e	e [+ATR]	.29[1]	7[1]	-8.6	7.2[1]	-4.5[1]
	ɛ [-ATR]	53.4	41.4	96.8	42	33.3
ɑ	ə [+ATR]	64.4	36.4	106	36.6	78.9
	ɑ [-ATR]	109	44.9	166	105	120.2
o	o [+ATR]	2.2	3.4[1]	5.2[1]	8.1[1]	-7.2
	ɔ [-ATR]	62.6	21.8	91.1	44	93.4
u	u [+ATR]	1.56	-7	45.9	-11.4	-21.2
	ʊ [-ATR]	22.3	-1.6[1]	11.7[1]	29.1[1]	50

In Kinande, as in Foodo and Ikposo, high vowel pairs tend not to have statistically significantly different ΔB1 means. In two cases, the high front vowels for speaker 1M-Kk and the high back vowels for speaker 2M-Ks, the [+ATR] vowel has the greater ΔB1 mean. On the other hand, in all but one case (1M-Kk) mid and low vowel pairs have statistically significantly different ΔB1 means, [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts. As for cross-height vowel pairs, only two pairs have statistically significantly different ΔB1 means: the front pair for 2M-Ks and the back pair for 4F-Jc. In both cases, the [-ATR] high vowel has a greater ΔB1 mean than the [+ATR] mid vowel. The B1 values of cross-height vowels are further considered below.

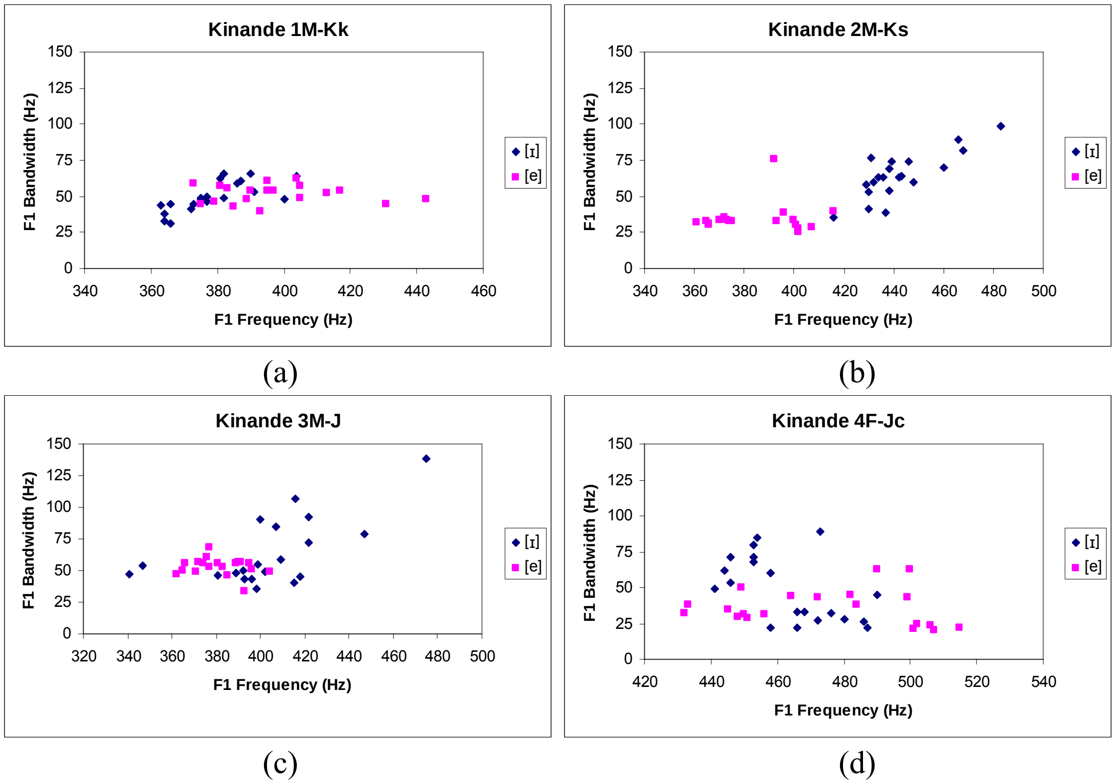


Figure 4.60: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ɪ]/[e] for Kinande speakers (a) 1M-Kk, (b) 2M-Ks, (c) 3M-J, and (d) 4F-Jc.

Figure 4.60 (a)-(d) displays scatterplots comparing F1 vs. B1 for cross height [-ATR] /ɪ/ and [+ATR] [e] for each of the Kinande speakers. Recall that in §4.2.3 the F1 mean values for these vowels were not significantly different for speakers 3M-J and 4F-Jc. Their bandwidth scatterplots, figures (c) and (d), also show considerable overlap of B1 values. Overlap of B1 is also very noticeable in the scatterplot of 1M-Kk (a) whose vowels have significant F1 mean differences. The bandwidth values for 2M-Ks in (b) also show some overlap.

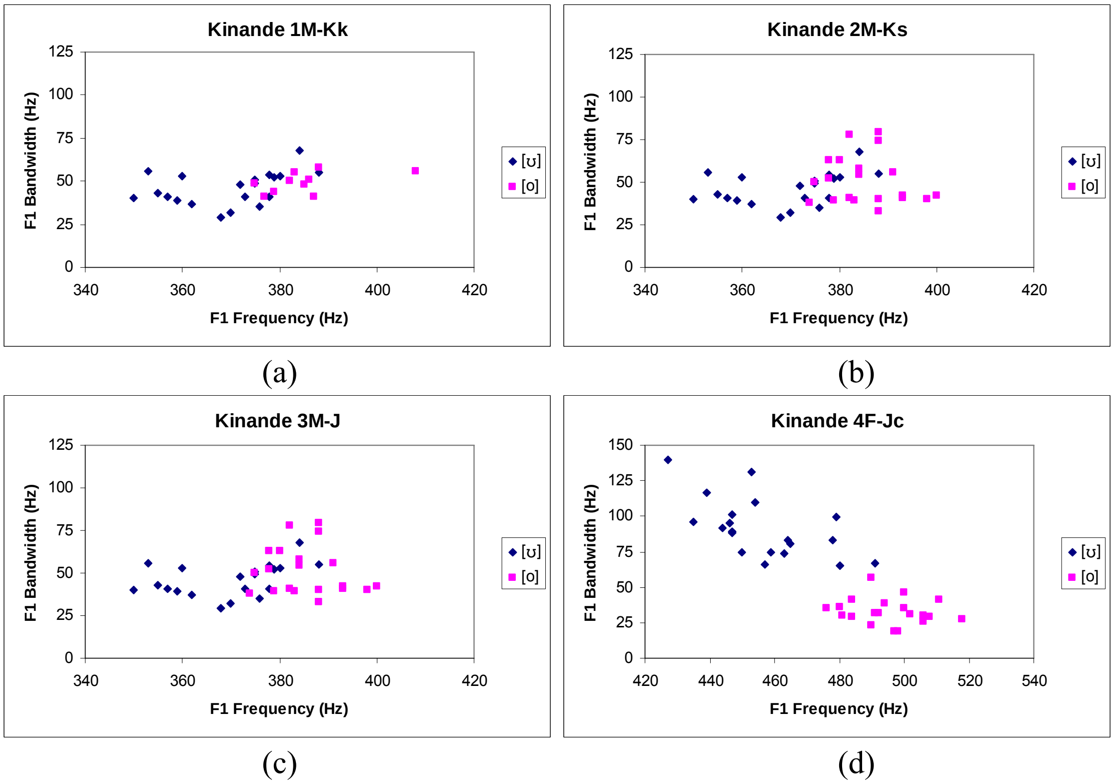


Figure 4.61: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ʊ]/[o] for Kinande speakers (a) 1M-Kk, (b) 2M-Ks, (c) 3M-J, and (d) 4F-Jc.

Figure 4.61 (a)-(d) displays scatterplots comparing F1 vs. B1 for cross height [-ATR] /ʊ/ and [+ATR] [o] for each of the Kinande speakers. In §4.2.3 the F1 mean values for these vowels were significantly different for speakers 2M-Ks and 4F-Jc, but there is considerable overlap of bandwidth values in the plots of 1M-Kk, 2M-Ks and 3M-J, figures (a)-(c) respectively. Only the plot of 4F-Jc (d), shows a clear separation of the bandwidth values for these two vowels with the [-ATR] high vowel have higher values than the [+ATR] mid vowel.

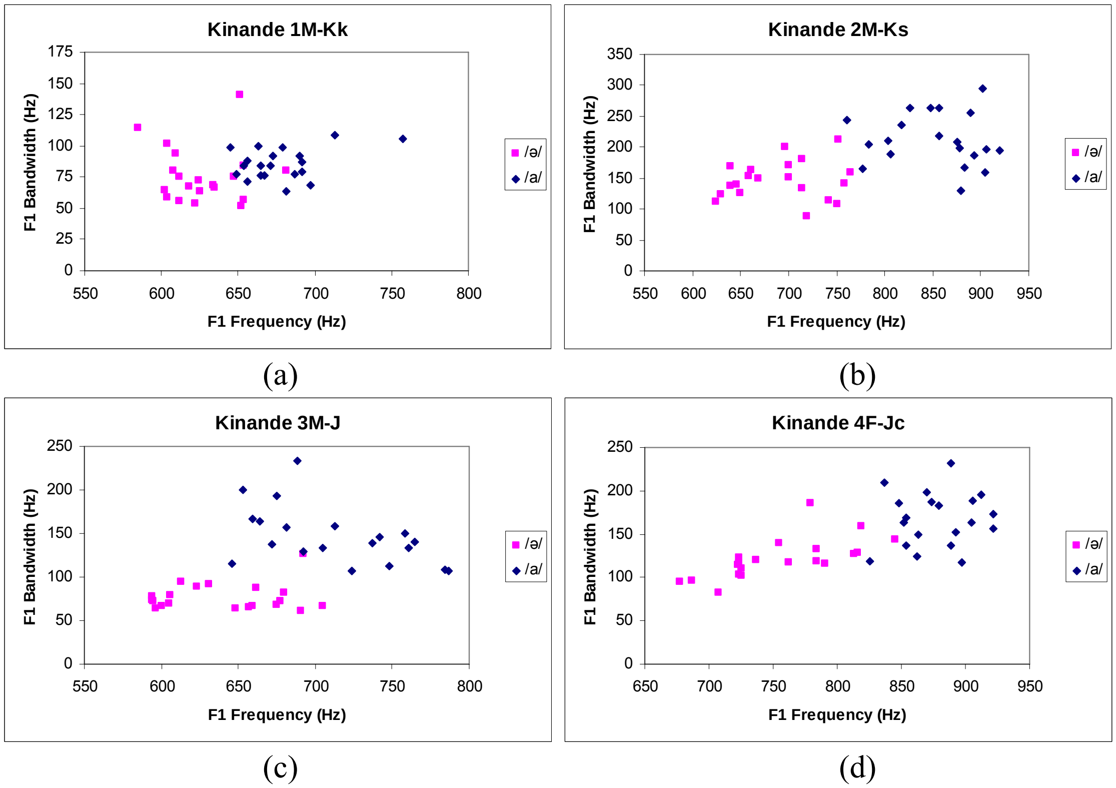


Figure 4.62: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ə]/[a] for Kinande speakers (a) 1M-Kk, (b) 2M-Ks, (c) 3M-J, and (d) 4F-Jc.

Figure 4.62 (a)-(d) displays scatterplots comparing F1 vs. B1 for [-ATR] /a/ and its [+ATR] [ə] variant for each of the Kinande speakers. In §4.2.3 the F1 mean values for these vowels were all statistically significant. In the plots of Figure 4.62, only the bandwidth values for speaker 3M-J show a tendency for the [-ATR] low vowel to have higher bandwidth frequencies than its [+ATR] variant, [ə].

To further investigate the cross-height vowel pairs as well as the low vowel and its [+ATR] variant, the F1 bandwidth (B1) values for all the vowels of the pooled data as well as of each speaker were submitted to a one-way ANOVA with B1 as the dependent variable and vowel quality as the independent factor. The results for the front and back cross-height vowels and for the low vowels are summarized in Table 4.41, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The main effect of Vowel Quality is significant (p=0.000) for the pooled data and for each speaker [Pooled $F(9,820)=88.26$; 1M-Kk $F(9,190) = 32.69$; 2M-Ks $F(9,200) = 87.54$; 3M-J $F(9,200) = 44.79$; 4F-Jc $F(9,200) = 108.74$].

Table 4.41: Kinande B1 Mean Values for Cross-height Vowels and [±ATR] Low Vowels for Each Speaker

Cells with the same degree of shading within columns indicate mean values which are not significant. Superscript numbers indicate vowels of the same phonological height whose B1 means are not significantly different

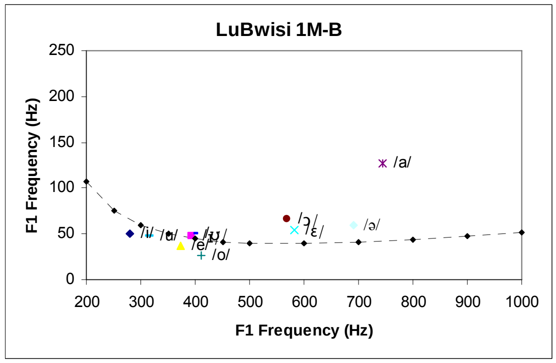
Vowel Quality	Pooled Data	1M-Kk	2M-Ks	3M-J	4F-Jc
ɪ [-ATR]	57^{1}	50^{1}	64^{1}	64^{1}	49
e [+ATR]	48^{2}	52^{1}	51^{1}	53^{1}	36^{1}
ə [+ATR]	105	76	147	77	122
a [-ATR]	153	86	212	147	167
o [+ATR]	46^{2}	49^{1}	51^{1}	52^{1}	33^{1}
ʊ [-ATR]	66^{1}	46^{1}	54^{1}	74^{1}	91

Beginning with an examination of the results for /a/ and its [+ATR] variant [ə], we see that the B1 mean values are significantly different for three of the four speakers as well as for the pooled data. Only in the case of 1M-Kk are the bandwidth means for these two vowels not significantly different. These results are especially interesting for 3M-J whose low vowels overlap considerably in the 660-700 Hz range. The mean B1 values for this speaker's [+ATR] low vowel are half those of the [-ATR] counterpart.

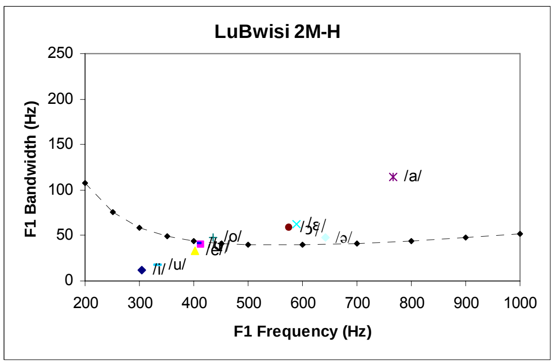
The results for the cross-height vowels appear to differ depending on gender. For the male speakers' data in Table 4.41, the B1 means for height 2 vowels, [-ATR] /ɪ ʊ/, are not significantly different than for those of height 3, [+ATR] [e o]. The bandwidth means for the female speaker, 4F-Jc and the pooled data have slightly different results. The back cross-height pair [ʊ]/[o] have significantly different B1 mean values. In the pooled data, the B1 mean values between the height 2 and 3 front vowels are not statistically significant just as the case was for the male speakers. Note that with the exception of 2M-Ks, whose front cross-height vowels [ɪ] and [e] proved not to have statistically significantly different B1 means, these results mirror those of ΔB1.

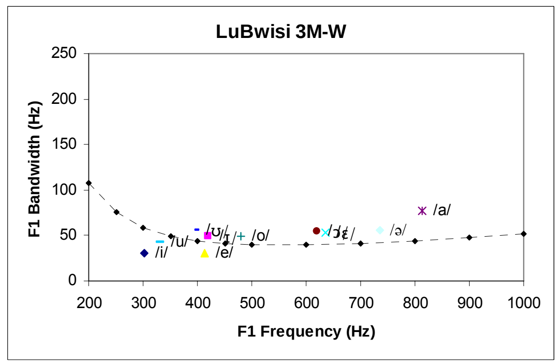
To test the effect of gender, the bandwidth values for the back cross-height pair were submitted to a univariate ANOVA with Vowel Quality and Gender as factors. As expected, Gender interacts significantly with Vowel Quality [$F(1,146)=73.12$, $p=0.000$]. The main effect of Quality is also significant [$F(1,146)=116.14$, $p=0.000$], which confirms that there may be a significant difference in the mean B1 values for this pair but that the effect is not consistent across gender.

4.3.4 LuBwisi

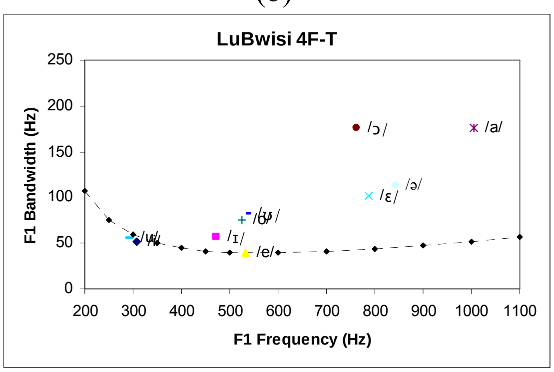


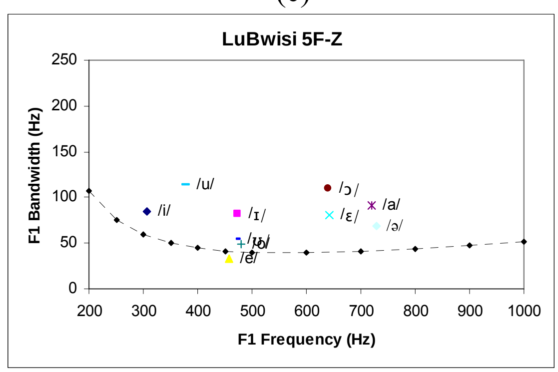
(a)





(b) (c)





(d) (e)

Figure 4.63: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for LuBwisi speakers (a) 1M-B, (b) 2M-H, (c) 3M-W, (d) 4F-T and (e) 5F-Z

Figure 4.63 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the LuBwisi speakers. Like Kinande, the vowel system of LuBwisi has seven contrastive vowels but ten surface forms. Of the languages with 9 or 10 surface vowels examined thus far, LuBwisi presents the best visual fit to bandwidth values as predicted by Fant's 1972 model. For example, speaker 3M-W's vowels all have mean B1 values very close to predicted values. The other male speakers, figures (a) and (b), do also, with the exception of [a], which have B1 means more than 70 Hz above the predicted values. The female speakers' vowels, however, again pattern differently than the males'. For 4F-T, low mid vowels and low vowels all have considerably higher B1 means than predicted values. In the case of speaker 5F-Z, all the vowels, with the exception of [+ATR] [e] have B1 means above predicted values. It is noteworthy, though, that many of the vowels have B1 means 30-60 Hz higher than predicted values. This type of offset from predicted values corresponds to differences between the bandwidths of males and females found in the Fujimura & Lindqvist (1971) study of Swedish, where the bandwidths of female speakers were some 20 Hz higher than for the male speakers. Moving the projected line up 20 Hz on the mean for speaker 5F-Z would produce a trajectory for the observed B1 values much like those of the others. The ΔB1 analysis sheds light on actually differences in the displacement of B1 from predicted values.

The ΔB1 values for the [ATR] harmony vowel pairs for the LuBwisi speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.4: Vowel Group (/i ɪ/, [e ɛ], [o ɔ] /u ʊ/ and [ə ɑ]), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] interacts significantly with both Gender and Vowel Group [$F(4,1128)=13.18$, $p=0.000$] and that main effect of

[ATR] is also significant [$F(1,1128)=276.27$, $p=0.000$]. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.42). [ATR] interacts significantly with Vowel Group in all five cases, and the main effect of [ATR] is significant for all speakers, [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.42: Univariate ANOVA Results for ΔB1 in LuBwisi

Mean differences are significant at $p \leq 0.002$; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-B	$F(4,220)=16.02$	$F(1,220)=188.94$	√
2M-H	$F(4,220)=4.33$	$F(1,220)=149.28$	√
3M-W	$F(4,220)= 10.93$	$F(1,220)= 138.29$	√
4F-T	$F(4,218)=5.28$	$F(1,218)=107.95$	√
5F-Z	$F(4,220)=28.44$	$F(1,220)=24.24$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(9,1138) = 64.11$; 1M-B $F(9,220) = 92.42$; 2M-H $F(9,220) = 51.3$; 3M-W $F(9,220) = 37.95$; 4F-T $F(9,218) = 43.72$;

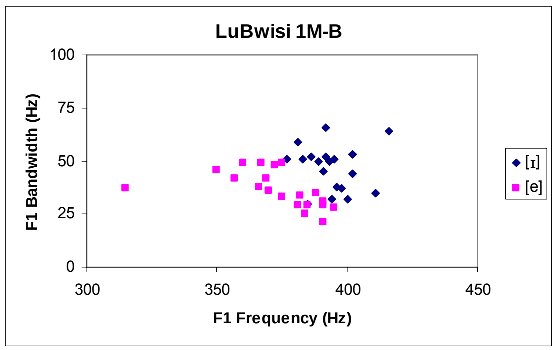
F(9,220) = 18.7]. In every case, *p*=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.43.

Table 4.43: LuBwisi ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different. Yellow highlighting indicates the [-ATR] vowel has a significantly lower mean that its [+ATR] counterpart.

Vowel Group	Vowel Quality	Pooled Data	1M-B	2M-H	3M-W	4F-T	5F-Z
i	i [+ATR]	-13.9	-13.9	-47.6	-28.7	-6.2	26.8
	ɪ [-ATR]	11.7	2.2[1]	-3.2[1]	5.8	13.3[1]	40.6
e	e [+ATR]	-8.6	-10.7[1]	-11.3[1]	-12.4	-.52[1]	-8.3
	ɛ [-ATR]	29.8	14.6	22.3	13.3	59.4	40.3
ɑ	ə [+ATR]	26.9	18.2	7.5	13.2	68.7	26.8
	ɑ [-ATR]	69.6	78.8	49.3	21.1	151	50
o	o [+ATR]	8.3[1]	-17.7	4.8[1]	8.4[1]	35.8[1]	10.2[1]
	ɔ [-ATR]	52.3	26	18.3	14.9	133	69.3
u	u [+ATR]	1.42	-8	-35.2	-11.1	-6.1	67.7
	ʊ [-ATR]	13.4[1]	5.3	-3.4[1]	10.5[1]	42.2[1]	12.7[1]

LuBwisi ΔB1 results are the most mixed seen so far in the languages with nine or ten surface vowels. Only front mid vowels have statistically significantly different ΔB1 means for all speakers. In every case, [-ATR] [ɛ] has the greater ΔB1 mean. However, high vowel pairs appear to fair better for ΔB1 in LuBwisi than thus seen. The same three speakers, 2M-H, 3M-W, and 4F-T all have [-ATR] high vowels with significantly higher ΔB1 means than their [+ATR] counterparts. In all cases, the [+ATR] vowels have a negative displacement from the predicted values. ΔB1 also appears to be particularly robust for the [ATR] pairs of speakers 2M-H and 4F-T. In the former case, four of five [ATR] pairs have statistically significantly different ΔB1 means, while in the latter, all five [ATR] pairs have statistically significantly different ΔB1 means. Cross-height vowel pairs, on the other hand, do not fare as well, with only three cases of ten having ΔB1 means that are significantly different. B1 values for cross-height vowels in LuBwisi are further considered below.



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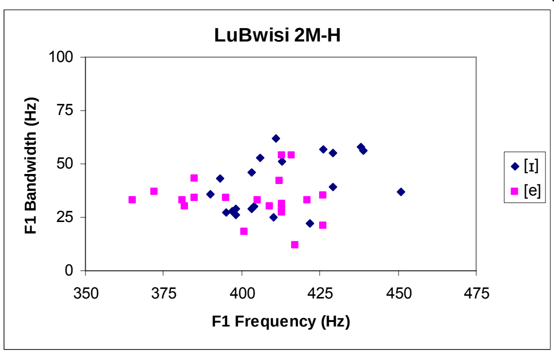

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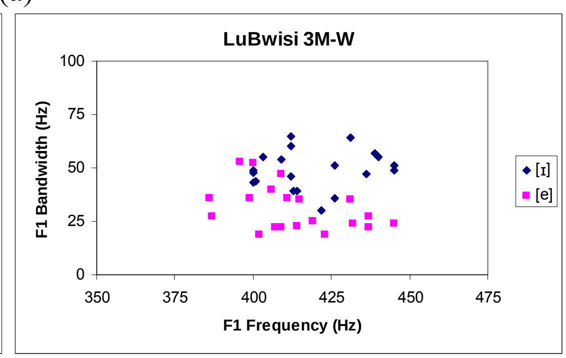

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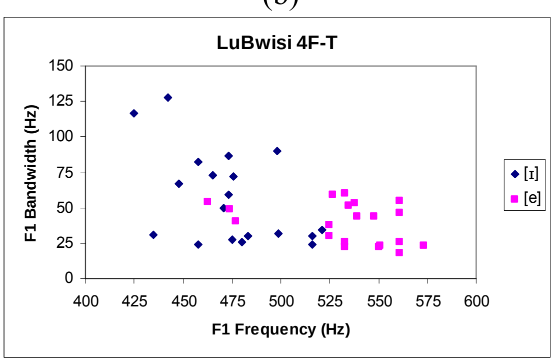

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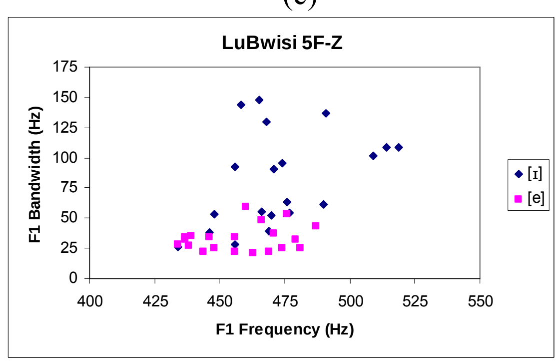


(e)

Figure 4.64: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ɪ]/[e] for LuBwisi speakers (a) 1M-B, (b) 2M-H, (c) 3M-W, (d) 4F-T and (e) 5F-Z.

Figure 4.64 (a)-(e) displays scatterplots comparing F1 vs. B1 for cross height [-ATR] /ɪ/ and [+ATR] [e] for each of the LuBwisi speakers. In §4.2.4 the F1 mean values for these vowels were significantly different only in the case of speaker 4F-T, figure (d). With the exception of speaker 5F-Z, figure (e), whose [-ATR] high vowel has mostly higher B1 values than her [+ATR] mid vowel, there is considerable overlap of B1 values for these vowels for all speakers.

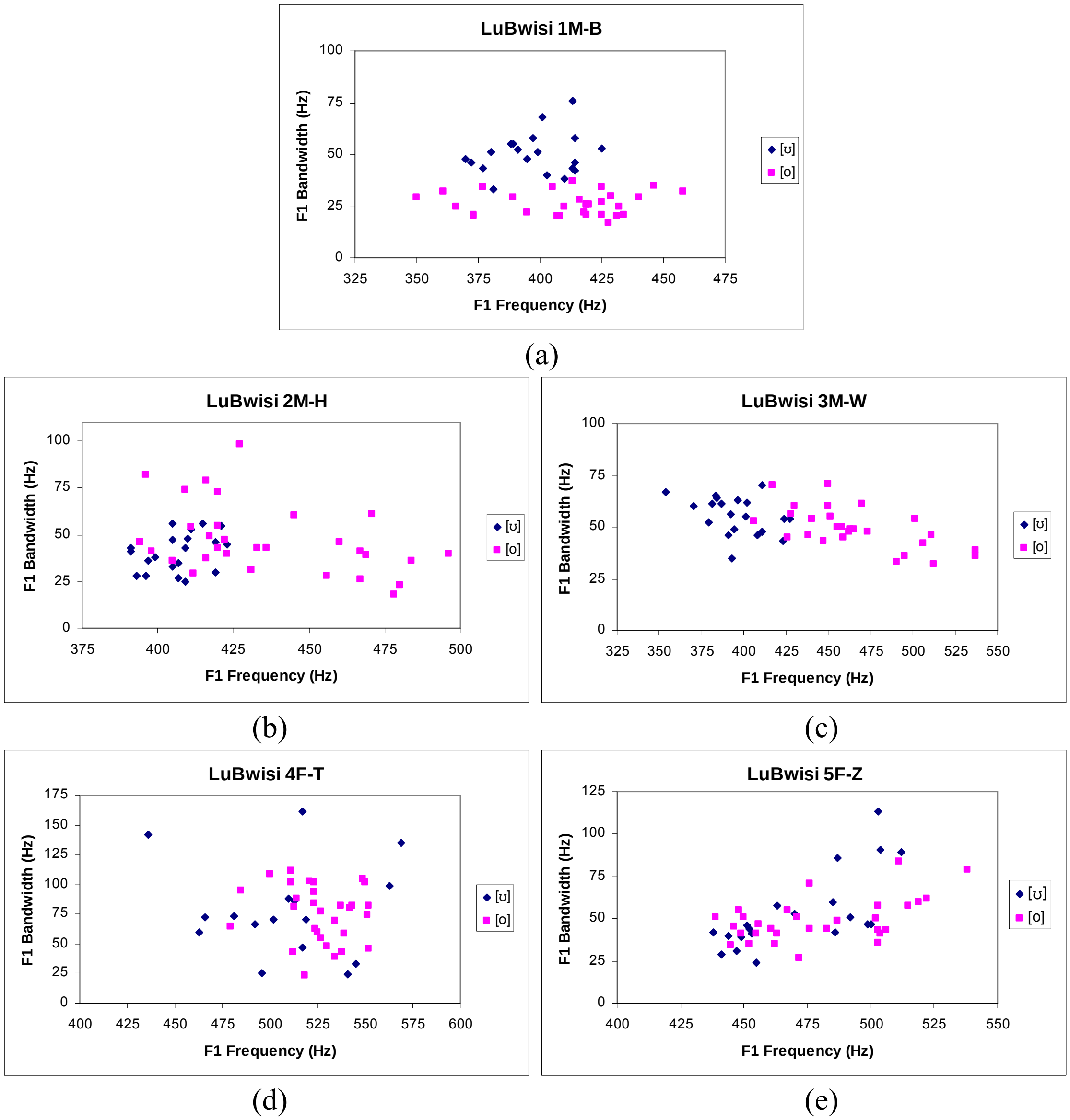


Figure 4.65: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ʊ]/[o] for LuBwisi speakers (a) 1M-B, (b) 2M-H, (c) 3M-W, (d) 4F-T and (e) 5F-Z.

Figure 4.65 (a)-(e) displays scatterplots comparing F1 vs. B1 for cross height [-ATR] /ʊ/ and for [+ATR] [o] of each of the LuBwisi speakers. In §4.2.4 the F1 mean values for this vowel pair were significantly different for speakers 2M-H and 3M-W.

Only in the case of 1M-B are the B1 values of [-ATR] high vowel consistently higher than the values of the [+ATR] mid vowel.

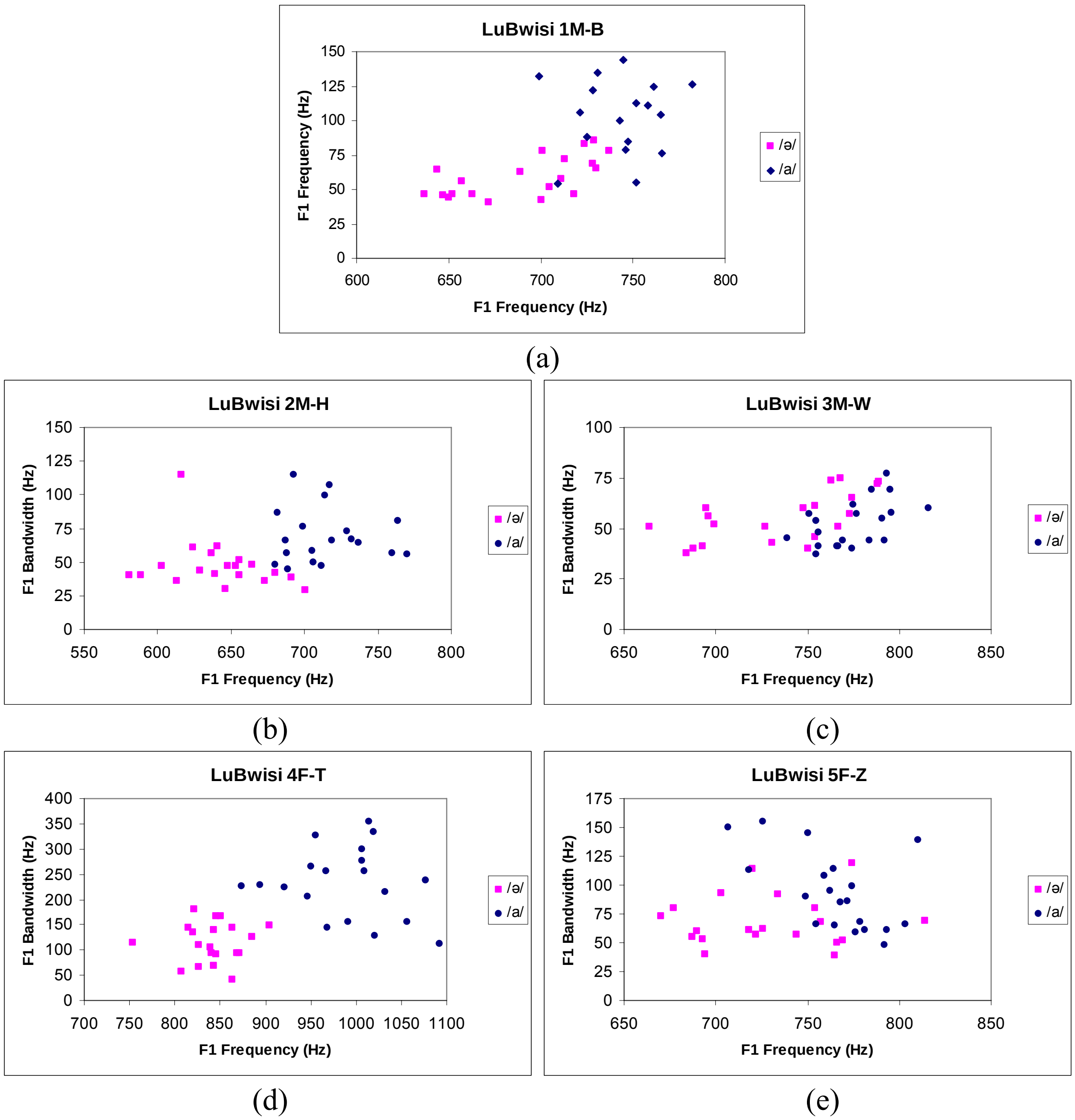


Figure 4.66: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pair [ə]/[a] for LuBwisi speakers (a) 1M-B, (b) 2M-H, (c) 3M-W, (d) 4F-T and (e) 5F-Z.

Figure 4.66 (a)-(e) displays scatterplots comparing F1 vs. B1 for [-ATR] /a/ and its [+ATR] [ə] variant and for each of the LuBwisi speakers. In §4.2.4 the F1 mean values for these vowels were significantly different in all cases, except for speaker 5F-Z (figure (e)): for this speaker, we see considerable overlap of both F1 and B1 values for these two vowels.

To further investigate the cross-height vowel pairs as well as the low vowel and its [+ATR] variant of the LuBwisi speakers, the F1 bandwidth (B1) values for all the vowels of the pooled data as well as of each speaker were submitted to a one-way ANOVA with B1 as the dependent variable and vowel quality as the independent factor. The results for the front and back cross-height vowels and for the low vowels are summarized in Table 4.44, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The main effect of Vowel Quality is significant (p=0.000) for the pooled data and for each speaker [Pooled $F(9,1138)=53.6$; 1M-B $F(9,220) = 77.23$; 2M-H $F(9,220) = 36.46$; 3M-W $F(9,220) = 20$; 4F-T $F(9,218) = 43.82$; 5F-Z $F(9,220) = 20.37$].

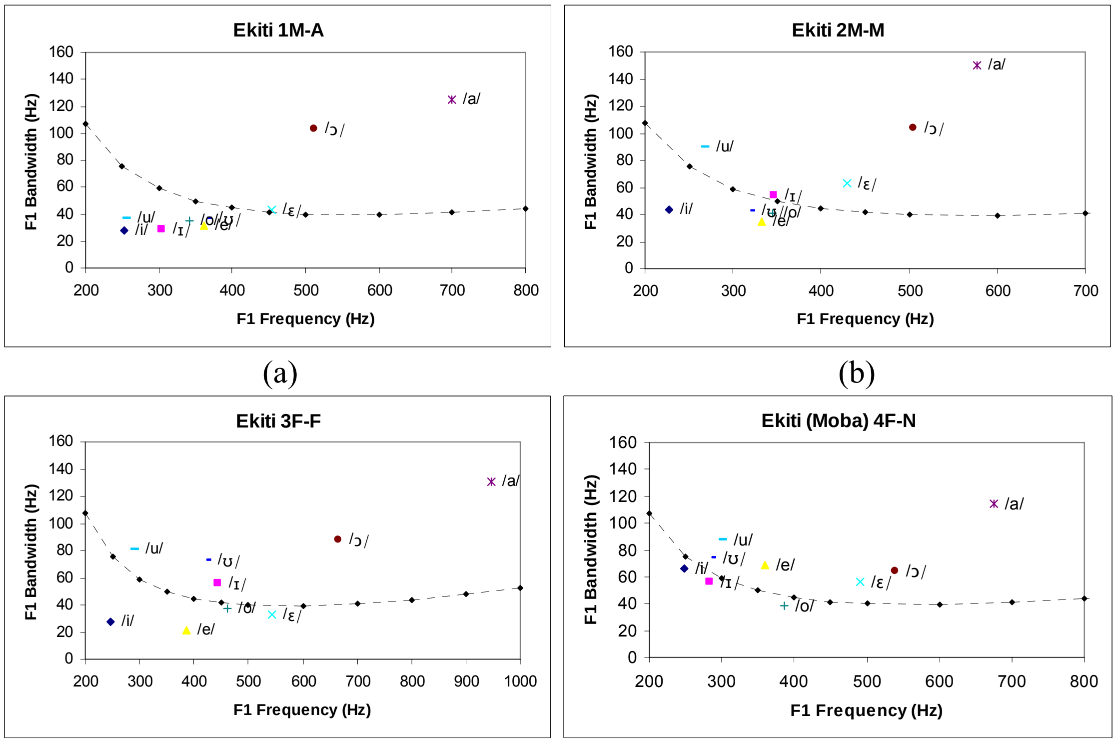
Table 4.44: LuBwisi B1 Mean Values for Cross-height Vowels and [±ATR] Low Vowels for Each Speaker

Cells with the same degree of shading within columns indicate mean values which are not significant. Superscript numbers indicate vowels of the same phonological height whose B1 means are not significantly different

Vowel Quality	Pooled Data	1M-B	2M-H	3M-W	4F-T	5F-Z
ɪ [-ATR]	56^{1}	47^{1}	40^{1}	49^{1}	62^{1}	81^{1}
e [+ATR]	35	36^{2}	33^{1}	31	39^{1}	33^{2}
ə [+ATR]	69	59	48	55	114	69
a [-ATR]	114	121	92	65	203	92
o [+ATR]	50	26^{2}	47^{1}	49	75^{1}	49^{2}
ʊ [-ATR]	56^{1}	50^{1}	41^{1}	55^{1}	82^{1}	54^{1}

The results of mean bandwidth comparisons for these three vowel pairs are the same as those found in the ΔB1 comparisons where considerable variation across speakers was noted. Speakers 2M-H and 4F-T pattern together - none of their mean B1 values for height 2 and 3 vowels are statistically significant. However, the mean B1 values for their low vowels are significantly different, with the [+ATR] low vowel having about one half the mean bandwidth of the [-ATR] low vowel. Speakers 3M-W and 5F-Z, on the other hand, pattern together. Mean B1 values for the front cross-height pair are significantly different but those for the low vowels are not. Speaker 1M-B patterns more with 2M-H and 4F-T in that the B1 means of his front cross-height pair are not significantly different but those of his low vowels are.

4.3.5 Ekiti-Yoruba



(a) (b)

(c) (d)

Figure 4.67: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Ekiti speakers (a) 1M-A, (b) 2M-M, (c) 3F-F and Mọba speaker (d) 4F-N

Figure 4.67 displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the Ekiti speakers, figures (a)-(c) and for the Mọba speaker (d). We shall consider the results for the Ekiti speakers first. The results for these speakers are similar in the following way: [+ATR] /i/ with B1 means 40 Hz or more below predicted values, [-ATR] back vowels with B1 means from 47 to 110 Hz above predicted values, and [+ATR] mid vowels with B1 means consistently below predicted values. The speakers differ, however, in the pattern of their height 2 and 3 vowels. The two males, figures (a) and (b) appear to have similar B1 means for these vowels, but the female, figure (c), has a clear separation between the [-ATR] high vowels and her [+ATR] mid vowels; the [-ATR] high vowels have B1 means approximately 35 Hz higher than the [+ATR] mid vowels.

The Mọba speaker, figure (d), differs from the others in that all her vowels, with the exception of low vowel /a/ have B1 means within 30 Hz of predicted values. Most notable is that the B1 mean of [+ATR] /i/ is very near the predicted value and that of [+ATR] /e/ is 20 Hz above the predicted value.

The ΔB1 values for the [ATR] harmony vowel pairs for the pooled Ekiti data (three speakers) were submitted to a univariate ANOVA with the same three factors as in §4.2.5: Vowel Group ([i ɪ], /e ɛ/, /o ɔ/ and [u ʊ]), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] interacts significantly with both Gender and Vowel Group [$F(3,463)=4.69$, $p=0.003$] and that main effect of [ATR] is also significant [$F(1,463)= 397.26$, $p=0.000$], [-ATR] vowels having greater ΔB1 means than [+ATR] vowels. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of ΔB1 includes three separate ANOVA, one for each Ekiti speaker (significance level set to 0.0167 for three comparisons), with [ATR] and Vowel Group as factors (Table 4.45). A separate univariate ANOVA was run for the Mọba speaker. [ATR] interacts significantly with Vowel Group in all four cases, but the main effect of [ATR] is significant only for the three Ekiti speakers, [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.45: Univariate ANOVA Results for ΔB1 in Ekiti and Mọba

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, *p*=0.000; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-A	*F*(3,152)=26.05	*F*(1,152)=488.25	√
2M-M	*F*(3,151)=57.26	*F*(1,151)=82.93	√
3F-F	*F*(3,152)=12.75	*F*(1,152)=167.23	√
4F-N	*F*(3,152)=8.12	*F*(1,152)=0.534	

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled Ekiti data: [Pooled Ekiti *F*(8,530)=97.54; 1M-A *F*(8,171) = 90.4; 2M-M *F*(8,170) = 81.02; 3F-F *F*(8,171) = 65.37; Mọba 4F-N *F*(8,171) = 20.54]. In every case, *p*=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.46.

Table 4.46: Ekiti and Mọba ΔB1 Mean Values by Vowel Group for Each Speaker

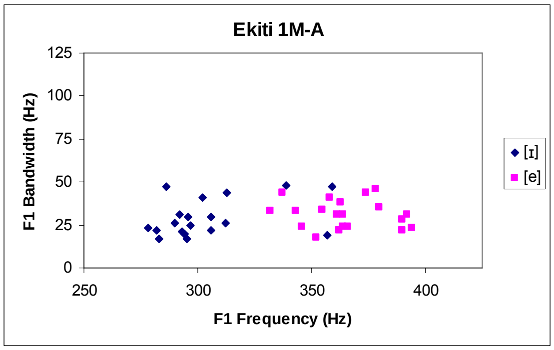
Shaded cells within vowel groups indicate mean values which are not significantly different. Superscript numbers indicate cross-height vowel means which are not significantly different. Yellow highlighting indicates the [-ATR] vowel has a significantly lower mean than its [+ATR] counterpart.

Vowel Group	Vowel Quality	Pooled (Ekiti)	1M-A	2M-M	3F-F	4F-N (Mọba)
i	i [+ATR]	-46.5	-46.6	-44	-49.2	-11.3
	ɪ [-ATR]	-4.3	-29.9[1]	3.1[1]	13.8	-10.9
e	e [+ATR]	-19.8	-17.1[1]	-17.6[1]	-24.6	19.8
	ɛ [-ATR]	5.2	2.1	20.3	-6.8	16.1
ɑ	ɑ [-ATR]	91.8	83.9	111	80.7	73.3
o	o [+ATR]	-10.2	-16[1]	-9.9[1]	-4.7	-7.6
	ɔ [-ATR]	58.4	63.3	64.1	47.7	25
u	u [+ATR]	.85	-37.3	20.7	19.1	28.9
	ʊ [-ATR]	2.3	-11.4[1]	-12.5[1]	30.1	11.4

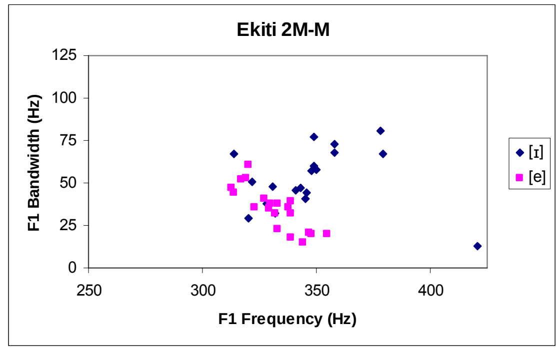
Like the results in LuBwisi, Ekiti ΔB1 results are mixed with only one mid-vowel [ATR] pair consistently exhibiting statistically significantly different ΔB1 means for all speakers. In every case, back [-ATR] [ɔ] has a greater ΔB1 mean than its [+ATR] counterpart. There is also a tendency for [-ATR] [ɛ] to have a greater ΔB1 mean than [+ATR] [e], as seen in the pooled data. This tendency, however, is reflected only in the vowels of speaker 2M-M. Five of six high vowel [ATR] pairs also have statistically significantly different ΔB1 means. However in the case of 2M-M's high back vowels, [+ATR] [u] has the greater ΔB1 mean.

Cross-height vowels do not have statistically significantly different ΔB1 means for either of the two male Ekiti speakers. In the case of 3F-F, the [-ATR] high vowel of both cross-height pairs has a statistically significantly different ΔB1 mean from its respective [+ATR] mid vowel partner. In both cases, the [-ATR] vowel has the greater ΔB1 mean. The B1 values for Ekiti cross-height vowels are further considered below.

In the case of the Mọba speaker (4F-N), only the back mid-vowel [ATR] pair has statistically significantly different ΔB1 means. As may well be expected, neither of the high vowel pairs have significantly different ΔB1 means.



(a)



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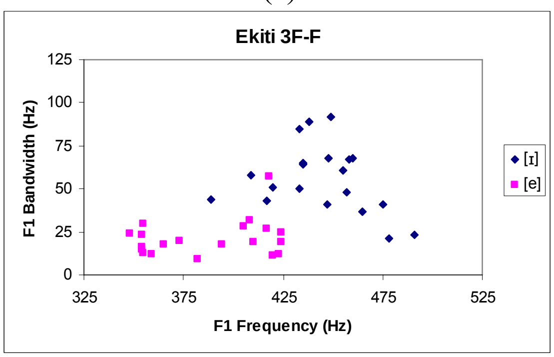
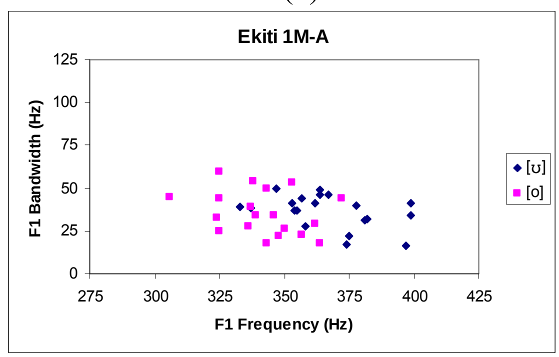
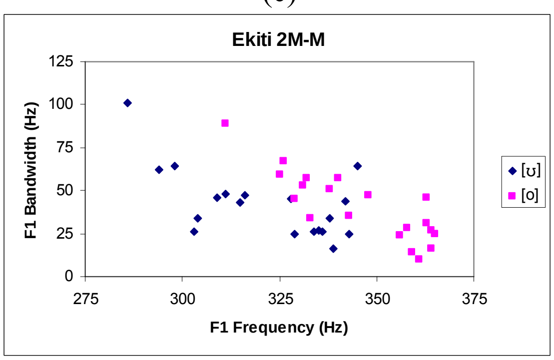


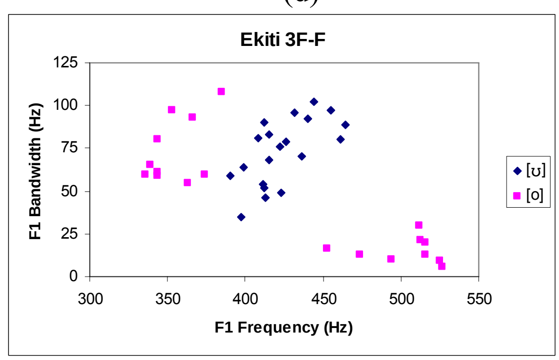
(c)



(d)



(e)



(f)

Figure 4.68: Scatter plots of F1 frequency vs. F1 Bandwidth for cross-height vowel pairs [ɪ]/[e] (a) 1M-A, (b) 2M-M, (c) 3F-F and [ʊ]/[o] (d) 1M-A, (e) 2M-M and (f) 3F-F for each Ekiti speaker

Figure 4.68 contains the scatterplots comparing F1 vs. B1 for the front and back cross height pairs for each of the three Ekiti speakers. [+ATR] /e/ and [-ATR] [ɪ] are found in figures (a)-(c) while [+ATR] /o/ and [-ATR] [ʊ] are found in figures (d)-(f).

From §4.2.5 we know that the F1 mean values for both of these pairs are significantly different for all three speakers. However, there is considerable overlap of the B1 values for both pairs, especially among the male speakers. The front cross-height pair for the female speaker, seen in figure (c), shows very little overlap for B1 while the back cross-height pair, seen in figure (f) shows mixed results: There is considerable overlap for B1 for those tokens occurring within the 350-450 Hz range for F1, but no overlap with those tokens whose F1 values are above 450 Hz.

To further investigate the cross-height vowel pairs, the F1 bandwidth (B1) values for all the vowels of the pooled Ekiti data as well as of each Ekiti speaker were submitted to a one-way ANOVA with B1 as the dependent variable and vowel quality as the independent factor.[49] The results for the front and back cross-height vowels are summarized in Table 4.47, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The main effect of Vowel Quality is significant (p=0.000) for the pooled data and for each speaker [Pooled $F(8,530)$=121.34; 1M-A1 $F(3,171)$ = 68.88; 2M-M $F(8,170)$ = 53.35; 3F-F $F(8,171)$ = 52.11].

[49] The data of the Ekiti Moba speaker, 4F-N, is excluded from this part of the analysis.

Table 4.47: Ekiti B1 Mean Values for Cross-height Vowels for Each Speaker

Cells with the same degree of shading within columns indicate mean values which are not significantly different. Superscript numbers indicate vowels of the same phonological height whose B1 means are not significantly different.

Vowel Quality	Pooled Data	1M-A	2M-M	3F-F
ɪ [-ATR]	46^{1}	29^{1}	54^{1}	56^{1}
e [+ATR]	29^{2}	31^{1}	35^{1}	21^{2}
o [+ATR]	38^{2}	35^{1}	41^{1}	37^{2}
ʊ [-ATR]	52^{1}	36^{1}	45^{1}	73^{1}

The results of the homogenous subsets confirm the observations made above. The B1 means for height 2 and 3 vowels, whether cross-height or within height, for the male speakers are not significantly different. These results conform also to the ΔB1 results discussed above. Not surprisingly, all of the vowels for speaker 1M-A, with the exception of /a/ and /ɔ/, (not shown in Table 4.47) form a single homogeneous subset. The latter two vowels form their own subset. As anticipated for the female speaker, the cross-height B1 means are statistically significant with the [-ATR] high vowels having higher means than the [+ATR] mid vowels. B1 means for height internal vowel pairs, however, are not significantly different.

4.3.6 Ifè

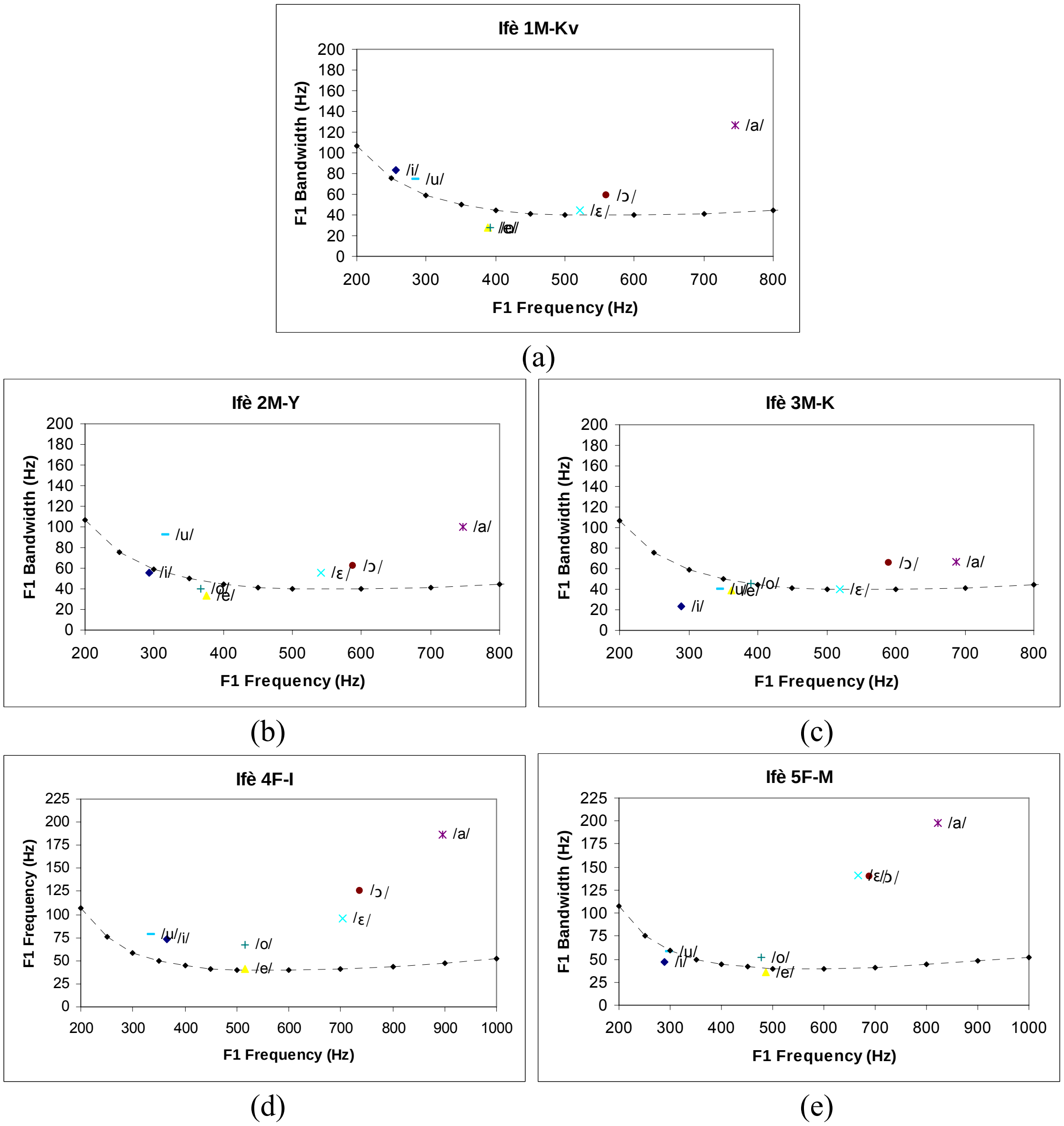


Figure 4.69: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Ifè speakers (a) 1M-Kv, (b) 2M-Y, (c) 3M-K, (d) 4F-I and (e) 5F-M

Figure 4.69 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the five Ifè speakers. Recall from

§2.2.2.2 Ifè has mid-vowel [ATR] harmony at the root level. In addition, Ifè exhibits coalescent [-ATR] harmony. Overall, the plots in Figure 4.69 for Ifè B1 means presents a picture not unlike that of the Mọba speaker in §4.3.5. [+ATR] vowels have B1 means within 37 Hz of predicted values. The Ifè speakers differ only in how their [-ATR] vowels behave. The main difference occurs between genders. All of the male speakers have [-ATR] mid vowels with B1 means close to predicted values. In contrast, none of the female speakers do. With the exception of speaker 3M-K, all of the speakers have B1 means for the low vowel 60-150 Hz above predicted values.

The ΔB1 values for the [ATR] harmony vowel pairs for the Ifè speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.6: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] does not interact significantly with Gender and Vowel Group [$F(1,399)=1.55$]. [ATR] and Gender, however, interact significantly [$F(1,399)=51.18$, $p=0.000$]. The main effect of [ATR] is also significant [$F(1,399)=216.03$, $p=0.000$], with [-ATR] vowels having greater ΔB1 means than [+ATR] vowels. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on gender.

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.48). [ATR] interacts significantly with Vowel Group in only one case, that of 1M-Kv. The main effect of [ATR] is significant for all speakers, [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.48: Univariate ANOVA Results for ΔB1 in Ifè

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, $p<0.01$; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-Kv	$F(1,70)=7.42$	$F(1,70)=91.7$	√
2M-Y	$F(1,70)=.128$	$F(1,70)=114.63$	√
3M-K	$F(1,73)=3.54$	$F(1,73)=15.79$	√
4F-I	$F(1,73)=.095$	$F(1,73)=64.03$	√
5F-M	$F(1,78)=.498$	$F(1,78)=46.97$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker (significance level set to .01 for five speakers) as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(6,700)=77.17$; 1M-Kv $F(6,126) = 47.39$; 2M-Y $F(6,150) = 52.62$; 3M-K $F(6,130) = 37.87$; 4F-I $F(6,128) = 40.62$; 5F-M $F(6,138) = 33.38$]. In every case, $p=0.000$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.49.

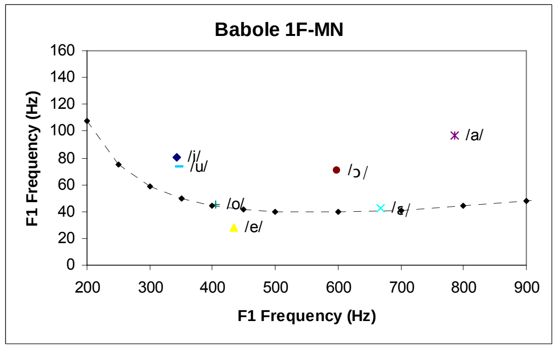
Table 4.49: Ifè ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significant.

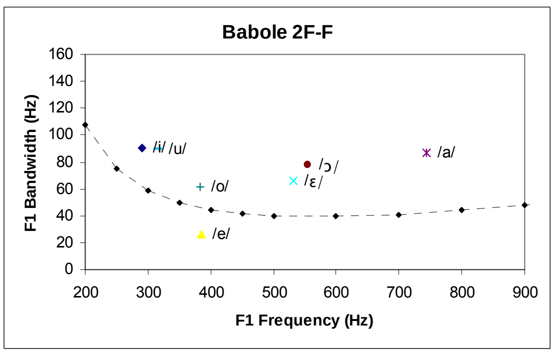
Vowel Group	Vowel Quality	Pooled Data	1M-Kv	2M-Y	3M-K	4F-I	5F-M
i	i [+ATR]	-4.9	9.8	-5.7	-39.4	24.7	-14.6
e	e [+ATR]	-8.5	-18.5	-13.7	-8.1	1.2	-2.3
	ɛ [-ATR]	33.3	2	15.9	0.74	54.2	100
ɑ	ɑ [-ATR]	94.2	84.3	57.8	26.2	138	152
o	o [+ATR]	2.3	-17.5	-9.6	1.2	27	13.7
	ɔ [-ATR]	50.7	19.2	22	26.1	84.3	97.2
u	u [+ATR]	11.6	11.3	35.7	-10.7	25.9	-2.7

In the overall model of Ifè ΔB1, [-ATR] mid vowels have greater ΔB1 means than their [+ATR] counterparts. In two cases only, the front [ATR] pair for speakers 1M-Kv and 3M-K, ΔB1 means fail to be statistically significantly different. When one-way ANOVA are run targeting only mid-vowel pairs (α=.01), the ΔB1 means for speaker 1M-Kv's front pair no longer form a homogeneous subset (i.e. they are reported to be significantly different).

4.3.7 Dibole



(a)



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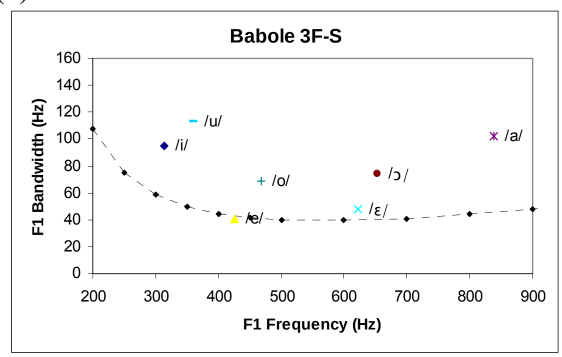

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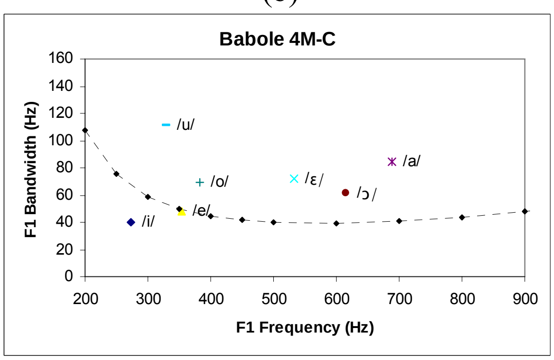
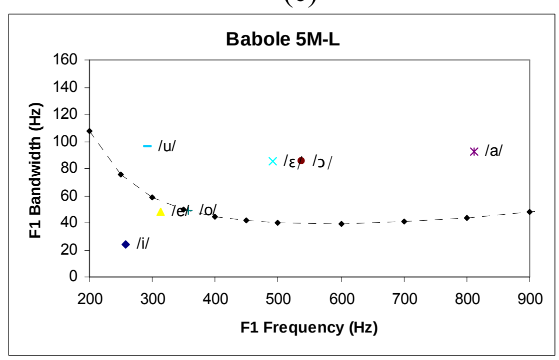


(d)



(e)

Figure 4.70: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Dibole speakers (a) 1F-MN, (b) 2F-F, (c) 3F-S, (d) 4M-C and (e) 5M-L

Figure 4.70 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the five Dibole speakers. Recall from

§2.2.1.2 that the Bantu C languages, such as Dibole, have a 7-vowel system with mid-vowel harmony. The plots of the B1 means in Figure 4.70 reveal something not seen so far in the study, namely a tendency for most of the vowels, regardless of [ATR] class to have B1 means higher than the predicted values. The male and female speakers differ in only one way: the manner in which [+ATR] front vowels are handled. The females tend to have B1 values for both [+ATR] high vowels well above predicted values, while the males tend to have the front vowel well below predicted values. Female speakers 1F-MN and 2F-F both have [+ATR] mid vowels with B1 means 20 Hz or more below the predicted values. The rest of the speakers have B1 means for these vowels very near the predicted values.

The ΔB1 values for the [ATR] harmony vowel pairs for the Dibole speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.7: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] interacts significantly with Gender and Vowel Group [$F(1,392)=4.00$, $p=0.046$] and that the main effect of [ATR] is also significant [$F(1,392)=206.62$, $p=0.000$], with [-ATR] vowels having greater ΔB1 means than [+ATR] vowels. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.50). [ATR] interacts significantly with Vowel Group in only one case, that of 4M-C. The main effect of [ATR] is significant for four of the five speakers, with [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts. The main effect of [ATR] is not significant for speaker 3F-S.

Table 4.50: Univariate ANOVA Results for ΔB1 in Dibole

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, p=0.000; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1F-MN	$F(1,76)=3.37$	$F(1,76)=48.75$	√
2F-F	$F(1,76)=6.54$	$F(1,76)=52.51$	√
3F-S	$F(1,76)=.363$	$F(1,76)=3.9$	
4M-C	$F(1,76)=28.99$	$F(1,76)=25.54$	√
5M-L	$F(1,76)=1.40$	$F(1,78)=278.58$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(6,713)=63.62$; 1F-MN $F(6,133) = 26.49$; 2F-F $F(6,153) = 18.75$; 3F-S $F(6,133) = 25.37$; 4M-C $F(6,133) = 31.32$; 5M-L $F(6,133) = 75.14$]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.51.

Table 4.51: Dibole ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1F-MN	2F-F	3F-S	4M-C	5M-L
i	i [+ATR]	4.1	29.2	28.4	38.3	-27.3	-48.1
e	e [+ATR]	-9.7	-15.3	-20.7	-2.4	-1.7	-8.6
	ɛ [-ATR]	22.6	1.8	25.9	8.4	32.2	44.7
ɑ	ɑ [-ATR]	48.9	52.5	44.2	56.4	43.7	47.9
o	o [+ATR]	13.5	1.2	15.5	28	23	-0.18
	ɔ [-ATR]	34.1	30.6	37.8	33.8	21.9	46.1
u	u [+ATR]	41.1	22.7	33.8	63.9	57.7	34.9

Within the overall model, ΔB1 is not as robust a measure in Dibole as in most of the other languages examined thus far. ΔB1 means for mid-vowel [ATR] pairs fail to be statistically significantly different in half of the cases (5 of 10). The number of statistically significantly different ΔB1 means improves somewhat when one-way ANOVA (with $\alpha = .01$) are run targeting the mid-vowel pairs only. The front mid-vowel and back mid-vowel pairs for speakers 1F-MN and 2F-F, respectively, no longer fall within the same homogeneous subset. Note that overall, the positive displacement of B1 from predicted values for [-ATR] mid vowels is not as great (mean of 22.6 Hz for pooled [ɛ] and mean of 34.1 Hz for pooled [ɔ]) as has been seen in the other languages thus far (Foodo being the one notable exception).

4.3.8 Mbosi

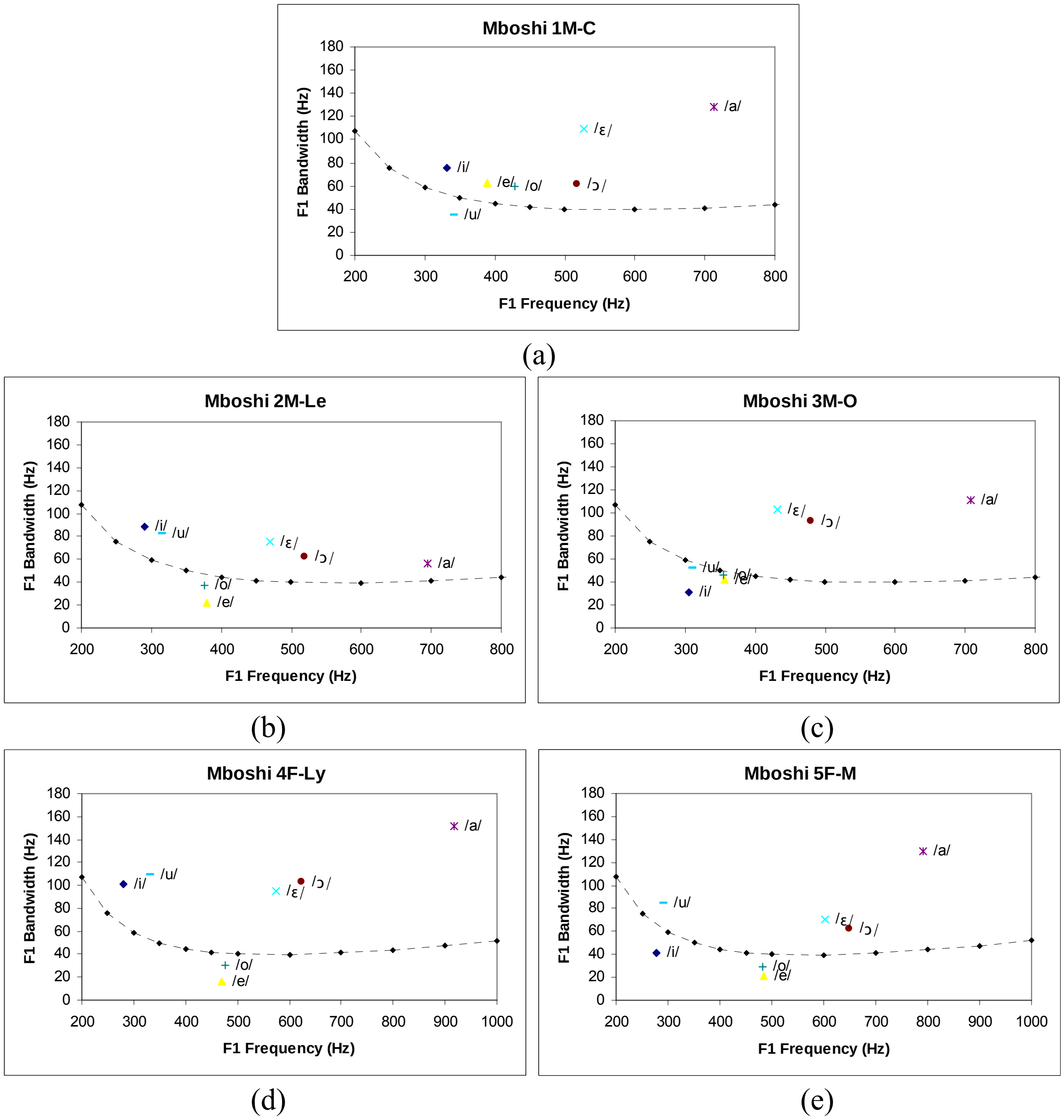


Figure 4.71: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Mbosi speakers (a) 1M-C, (b) 2M-Le, (c) 3M-O, (d) 4F-Ly and (e) 5F-M

Figure 4.71 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the five Mbosi speakers. A clearer pattern of B1 emerges for the Mbosi speakers than what was seen for the Dibole speakers. Concentrating specifically on the [ATR] harmony pairs, we see that there is a tendency for the [+ATR] mid vowels to have B1 means at or below the predicted values. Speaker 1M-C is the only exception. In contrast, [-ATR] mid vowels B1 means range much higher overall than the predicted means, as well as up to 50-80 Hz higher than their [+ATR] counterparts. This effect is most noticeable in speakers 3M-O and 4F-Ly.

One more notable difference between the Dibole and Mbosi bandwidth data is in the B1 means of the low vowel. While it is true that for Dibole the B1 means of the low vowel tended to be at least 50 Hz above the predicted means, for four of the five Mbosi speakers the B1 means range 70-100 Hz above predicted values. It is interesting to note that according to Leitch (1996), Mbosi is the only known example of a Bantu C language in which the low vowel /a/ is specified for [RTR]. In other words, it is the only Bantu C language in which /a/ induces [-ATR] harmony. It may be tempting to suggest that the high B1 mean values for /a/ in Mbosi provide evidence for an acoustic correlate which supports the phonological category privative [RTR]. However, as it will be seen in the B1 results for the Oroko languages, where /a/ does not induce [-ATR] harmony, several speakers have B1 means for /a/ within the 70-100 Hz range.

The ΔB1 values for the [ATR] harmony vowel pairs for the Mbosi speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.8: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] does not interact significantly with Gender and

Vowel Group [$F(1,372)=2.48$]. However, [ATR] does interact significantly with Gender [$F(1,372)=7.66$, $p=0.006$]. The main effect of [ATR] is also significant [$F(1,372)=542.24$, $p=0.000$], with [-ATR] vowels having greater ΔB1 means than [+ATR] vowels. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on gender.

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.52). [ATR] interacts significantly with Vowel Group in only two cases, that of 1M-C and 2M-Le. The main effect of [ATR] is significant for all speakers, [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.52: Univariate ANOVA Results for ΔB1 in Mbosi

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, $p\leq 0.001$; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-C	$F(1,66)=23.54$	$F(1,66)=34.51$	√
2M-Le	$F(1,76)=11.75$	$F(1,76)=252.68$	√
3M-O	$F(1,66)=2.31$	$F(1,66)=234.16$	√
4F-Ly	$F(1,76)=.927$	$F(1,73)=459.95$	√
5F-M	$F(1,76)=3.37$	$F(1,76)=85.64$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(6,671)=104.9$; 1M-C $F(6,123)$ =

49.32; 2M-Le $F(6,132) = 26.62$; 3M-O $F(6,123) = 97.77$; 4F-Ly $F(6,133) = 91.1$; 5F-M $F(6,132) = 58.2$]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.53.

Table 4.53: Mbosi ΔB1 Mean Values by Vowel Group for Each Speaker

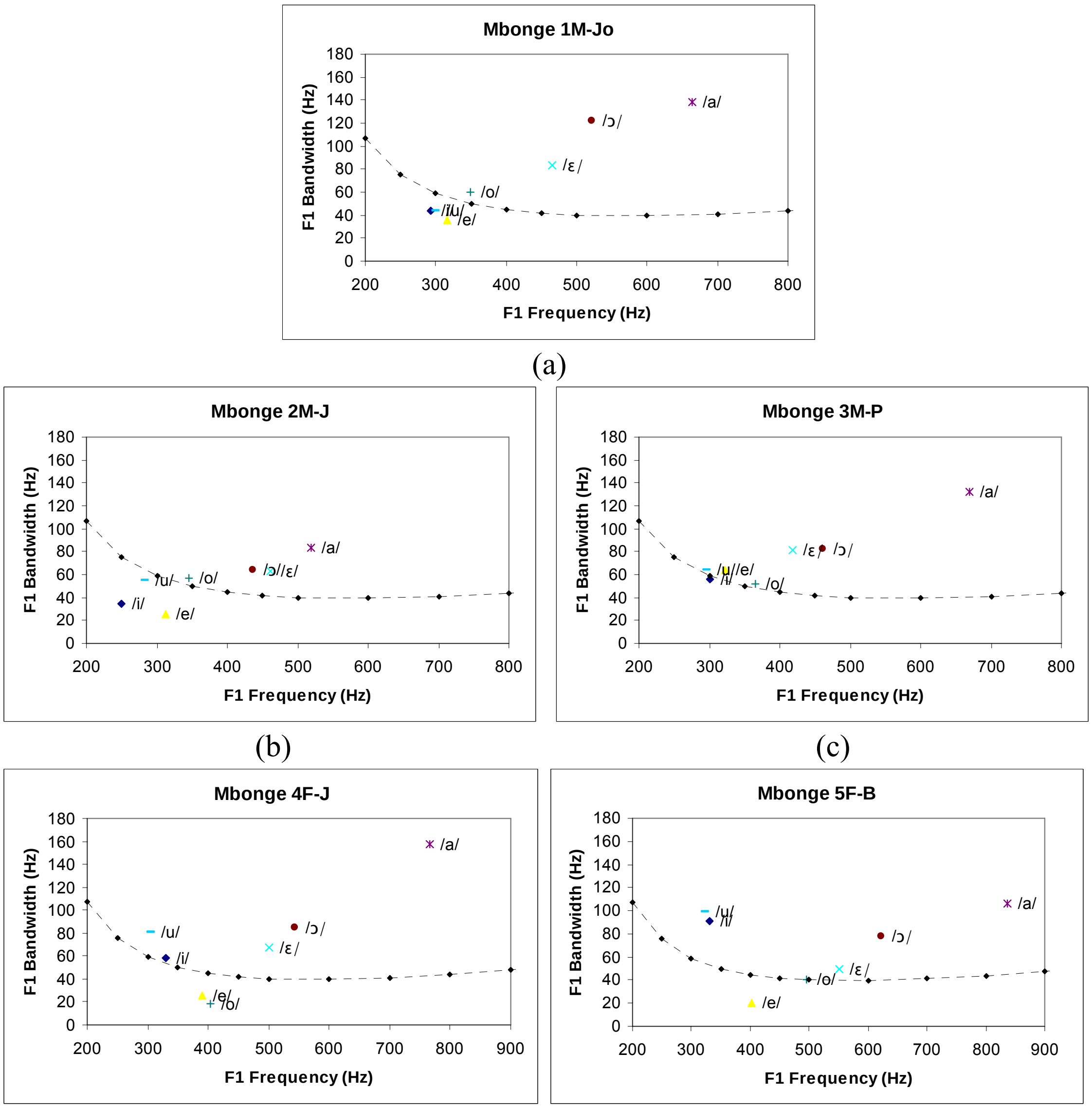
Shaded cells within vowel groups indicate mean values which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-C	2M-Le	3M-O	4F-Ly	5F-M
i	i [+ATR]	7.2	22.7	28.8	-26.8	36.2	-23.8
e	e [+ATR]	-11.5	17.3	-24.5	-7.1	-24.6	-18.8
	ɛ [-ATR]	50.4	69.9	34.9	60.2	55.9	31.1
ɑ	ɑ [-ATR]	72.1	86.9	15.4	69.8	103	85.4
o	o [+ATR]	-6.2	16.8	-10	-3	-10.3	-11.3
	ɔ [-ATR]	36.3	21.8	22.4	52.1	63.3	22
u	u [+ATR]	16.8	-16.7	26.2	-4.5	56.2	23.5

In contrast to Dibole, ΔB1 is a robust measure in Mbosi. With the exception of the back mid-vowel [ATR] pair for speaker 1M-C, all mid-vowel pairs have statistically significantly different ΔB1 means. [-ATR] mid vowels have greater ΔB1 means than their [+ATR] counterparts. With the exception of speaker 1M-C, all [+ATR] mid vowels have ΔB1 means below the predicted values as well as overall greater positive displacement of B1 from predicted values for [-ATR] [ɛ] than what was seen in Dibole.

In addition, the absolute difference in ΔB1 means in Mbosi ranges from 50 – 80 Hz for front vowel [ATR] pairs and 32 – 73 Hz for back vowel [ATR] pairs. Absolute difference in ΔB1 means in Dibole is much less: 17 – 53 Hz for front vowel [ATR] pairs and 22 – 46 Hz for back vowel [ATR] pairs. These kinds of differences are also reflected in the low vowel [ɑ] which in the pooled data has a ΔB1 mean of 72.1 Hz in Mbosi versus a ΔB1 mean of 48.9 Hz in the pooled data of Dibole.

4.3.9 Mbonge



(a)

(b) (c)

(d) (e)

Figure 4.72: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Mbonge speakers speakers (a) 1M-Jo, (b) 2M-J, (c) 3M-P, (d) 4F-J and (e) 5F-B

Figure 4.72 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the five Mbonge speakers. Among the male speakers of Mbonge, figures (a)-(e) there is a tendency for the [+ATR] vowels to have B1 means near or below the predicted values. The women display the tendency for high vowels to have B1 means higher than predicted values, but for the [+ATR] mid vowels to have means near or below predicted values. How the [-ATR] vowels are handled is more speaker idiosyncratic rather than gender based. Speakers 1M-Jo and 4F-J have [-ATR] mid vowels with B1 means considerably higher than their [+ATR] counterparts: [ɛ] ranges 50-60 Hz higher than [e] and [ɔ] 70-90 Hz higher than [o]. The B1 differential of [±ATR] mid vowels for the other speakers, however, is 38 Hz or less. For all speakers, the B1 mean of the low vowel is higher than that of other vowels. The amount of displacement from predicted values depends on speaker. Speakers 1M-Jo, 3M-P, and 4F-J have B1 means 90 Hz or more above predicted values while the other two have B1 means in the 40-60 Hz range above predicted value.

The ΔB1 values for the [ATR] harmony vowel pairs for the Mbonge speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.9: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] interacts significantly with Gender and Vowel Group [$F(1,404)=6.43$, $p=0.012$]. The main effect of [ATR] is also significant [$F(1,404)=400.67$, $p=0.000$], with [-ATR] vowels having greater ΔB1 means than [+ATR] vowels. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.54). [ATR] interacts significantly in two of the five cases (2M-J and 4F-J). The main effect of [ATR] is significant for all speakers, with [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.54: Univariate ANOVA Results for ΔB1 in Mbonge

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, $p \leq 0.001$; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-Jo	$F(1,82)=1.81$	$F(1,82)=162.45$	√
2M-J	$F(1,79)=26.16$	$F(1,76)=83.77$	√
3M-P	$F(1,80)=2.5$	$F(1,78)=111.12$	√
4F-J	$F(1,78)=13.08$	$F(1,78)=261.84$	√
5F-B	$F(1,75)=1.6$	$F(1,76)=56.14$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(6,709) = 143.63$; 1M-Jo $F(6,142) = 99.37$; 2M-J $F(6,136) = 71.33$; 3M-P $F(6,137) = 73.04$; 4F-J $F(6,135) = 60.36$; 5F-B $F(6,131) = 28.97$]. In every case, $p=0.000$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.55.

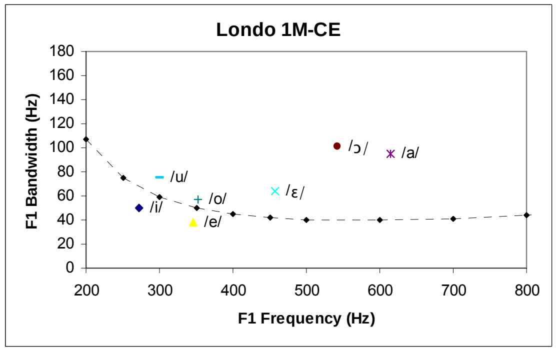
Table 4.55: Mbonge ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different.

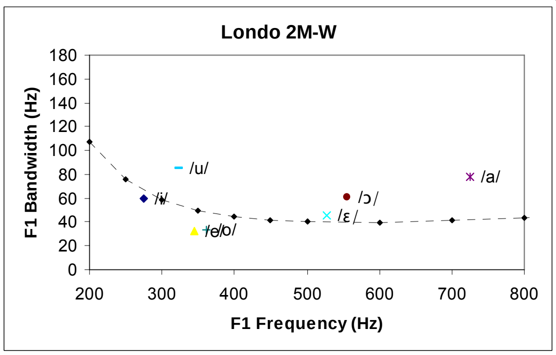
Vowel Group	Vowel Quality	Pooled Data	1M-Jo	2M-J	3M-P	4F-J	5F-B
i	i [+ATR]	-4.1	-16.2	-40.6	-3.7	5.3	36.6
e	e [+ATR]	-16	-19.9	-31.4	9.3	-18.2	-19.1
	ɛ [-ATR]	27.5	38.8	20.6	37.8	27.1	9.8
ɑ	ɑ [-ATR]	81.6	97.7	43.4	92.1	114	60.9
o	o [+ATR]	-2	9.1	6.8	2.9	-26.1	-3.1
	ɔ [-ATR]	45.5	81.7	21.6	41.5	45.3	37.6
u	u [+ATR]	8.6	-15	-8.6	4	22.4	42.3

ΔB1 mean differences for Mbonge mid-vowel [ATR] pairs are consistently significant. [-ATR] mid vowels have greater ΔB1 means than their [+ATR] counterparts. A one-way ANOVA targeting only the mid vowel pairs for speaker 2M-J does not improve the model.

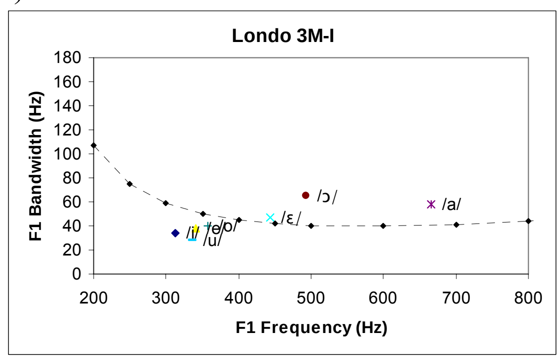
4.3.10 Londo



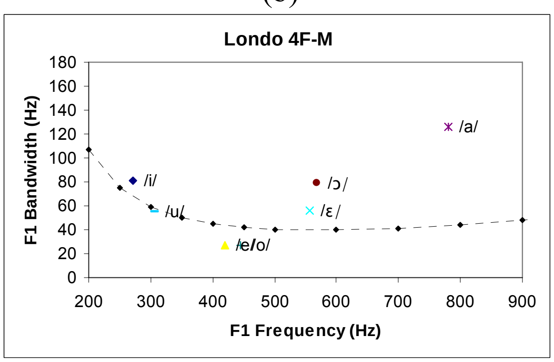
(a)



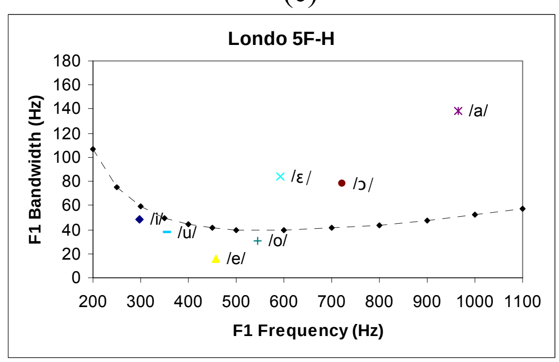
(b)



(c)



(d)



(e)

Figure 4.73: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Londo speakers (a) 1M-CE, (b) 2M-W, (c) 3M-I, (d) 4F-M and (e) 5F-H

Figure 4.73 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the five Londo speakers. Londo presents a close fit of observed B1 means to the predicted values. This is true especially for male speakers 2M-W and 3M-I. The same tendency is also seen in front vowels for speakers 1M-C and 4F-M. There is also the tendency seen elsewhere for [+ATR] mid vowels to have B1 mean values lower than predicted values. The B1 means for the [ATR] harmony pairs for the two female speakers, seen in figures (d) and (e), resemble the kinds of differences noted for Mbosi (Bantu C). The low vowel for the females also patterns like what was seen in Mbosi, where B1 mean values were 70-100 Hz above the predicted values.

The ΔB1 values for the [ATR] harmony vowel pairs for the Londo speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.10: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] does not interact significantly with Gender and Vowel Group [$F(1,386)=3.93$]. [ATR] and Gender, however, interact significantly [$F(1,386)=15.98$, $p=0.000$] and the main effect of [ATR] is also significant [$F(1,386)=385.06$, $p=0.000$]. These results would indicate that while the effect of [ATR] on the ΔB1 values is statistically significant, it patterns differently depending on gender.

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.56). These results indicate that [ATR] does not interact with Vowel Group for any of the speakers. The main effect of [ATR], however, is significant, with [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.56: Univariate ANOVA Results for ΔB1 in Londo

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, p=0.000; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-CE	$F(1,76)=5.13$	$F(1,72)=113.39$	√
2M-W	$F(1,72)=5.67$	$F(1,72)=83.09$	√
3M-I	$F(1,74)=6.11$	$F(1,78)=79.2$	√
4F-M	$F(1,76)=4.34$	$F(1,76)=74.04$	√
5F-H	$F(1,76)=6.26$	$F(1,76)=143.79$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(6,677) = 117.79$; 1M-CE $F(6,133) = 40.86$; 2M-W $F(6,125) = 33.25$; 3M-I $F(6,131) = 26.5$; 4F-M $F(6,127) = 46.68$; 5F-H $F(6,133) = 69.91$]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.57.

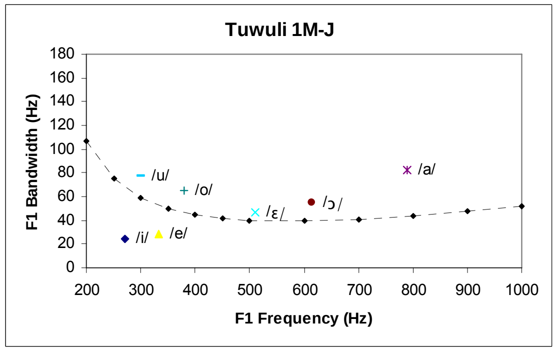
Table 4.57: Londo ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different.

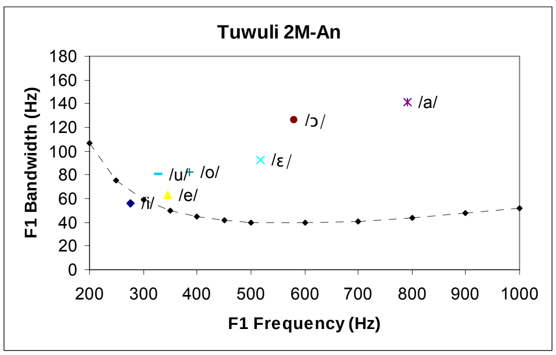
Vowel Group	Vowel Quality	Pooled Data	1M-CE	2M-W	3M-I	4F-M	5F-H
i	i [+ATR]	-11.2	-16.8	-7.1	-23.4	9.1	-11.8
e	e [+ATR]	-17.1	-12.5	-18	-13.1	-16.5	-25.4
	ɛ [-ATR]	18.9	22.8	5.2	5.6	16.9	44.2
ɑ	ɑ [-ATR]	56.2	55.7	36.4	17.8	83	88
o	o [+ATR]	-8.4	7	-18.7	-8.3	-14.9	-9.1
	ɔ [-ATR]	36.7	61.6	20.9	24.7	39.9	36.4
u	u [+ATR]	-0.02	14.9	29.1	-24	-3.1	-11.3

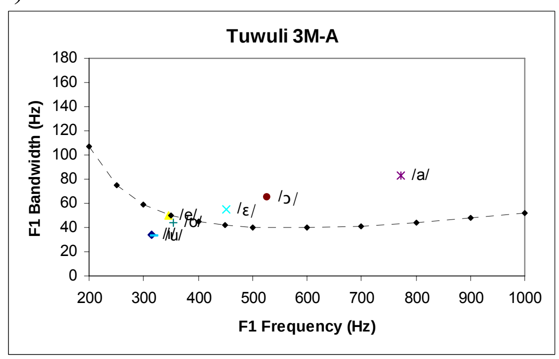
As in Mbonge, ΔB1 means for Londo mid-vowel [ATR] pairs are consistently significantly different, [-ATR] mid vowels having greater ΔB1 means than their [+ATR] counterparts. A one-way ANOVA targeting only the mid vowel pairs for speaker 3M-I does not improve the model. Both Londo and Mbonge have similar ranges in absolute difference in ΔB1 means for mid-vowel [ATR] pairs: 23 – 69 Hz in Londo and 29 – 72 Hz in Mbonge.

4.3.11 Tuwuli



(a)





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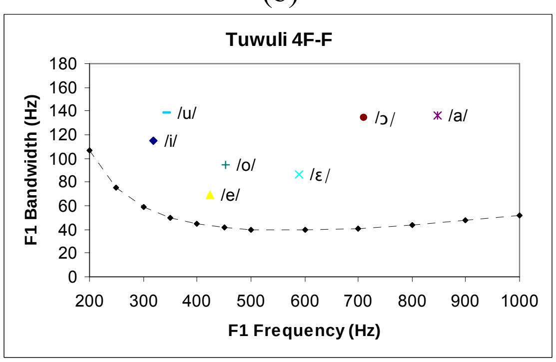

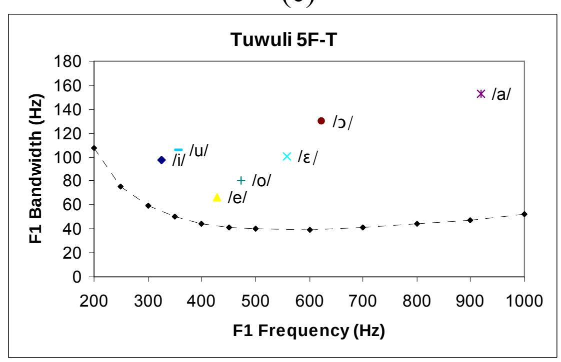

(d) (e)

Figure 4.74: Plots of mean F1 frequency and mean F1 bandwidth in Hz for each vowel with predicted B1 values for F1 based on Fant's (1972) formula for modeling the effects of various losses within the vocal tract (dotted line) for Tuwuli speakers (a) 1M-J, (b) 2M-An, (c) 3M-A, (d) 4F-F and (e) 5F-T

Figure 4.74 (a)-(e) displays the plots of the mean F1 frequency versus the mean B1 frequency (F1 bandwidth) for the vowels of the five Tuwuli speakers. Figure 4.74 demonstrates a clear difference between the males and females in the dispersion of the

B1 means of Tuwuli vowels. The B1 values for the male speakers tend to hover near predicted B1 values. This is true especially for 1M-J and 3M-A, figures (b) and (c) respectively, whose [-ATR] mid vowels have B1 means within 25 Hz of the predicted values.

The vowels of the females, however, all have B1 mean values much higher than the predicted values. Even the vowel with the lowest B1 mean, [+ATR] /e/ is more than 20 Hz higher than the predicted value. It is possible that the size of the females' vocal tracts is contributing to this offset. A similar effect has already been noted for speaker 5F-Z of LuBwisi in §4.3.4 where it was suggested, following Fujimura & Lindqvist 1971, that female speakers can exhibited bandwidths some 20 Hz or more higher on the mean than males.

Lastly, for the two female speakers and one of the male speakers, 2M-An, the [-ATR] mid vowels have much higher B1 means than the predicted values in comparison to their [+ATR] counterparts. This effect is most pronounced among the back vowels where the differential is 40 Hz or more. For the other two speakers, 1M-J and 3M-A, the differential is 20 Hz or less and in one case, a [-ATR] vowel has a lower B1 mean than its [+ATR] counterpart.

The ΔB1 values for the [ATR] harmony vowel pairs for the Tuwuli speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.11: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that [ATR] does not interact significantly with Gender and Vowel Group in the three-way analysis [$F(1,390)=2.61$]. In the two-way analyses, [ATR] and Gender do not interact significantly [$F(1,390)=3.34$] and neither do [ATR] and Vowel Group [$F(1,390)=1.63$]. The main effect of [ATR], however, is significant [$F(1,390)=132.24$, $p=0.000$], with [-ATR] vowels having greater ΔB1 means than [+ATR] vowels.

Since there were no significant two-interactions with [ATR] within the above model, another univariate ANOVA model was run that replaced Gender with Speaker. In this model, [ATR] interacts significantly with Speaker and Vowel Group [$F(1,390)=5.43$, $p=0.000$].

Further investigation of ΔB1 includes five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.58). [ATR] interacts significantly with Vowel Group in two cases, that of 1M-J and 4F-F. The main effect of [ATR] is significant for all speakers with [-ATR] vowels having greater ΔB1 means than their [+ATR] counterparts.

Table 4.58: Univariate ANOVA Results for ΔB1 in Tuwuli

Shaded cells indicate mean differences that are not significant. Where mean differences are significant, $p<0.01$; a check indicates that the ΔB1 mean for the [-ATR] vowel is greater than the ΔB1 mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-J	$F(1,76)=32.21$	$F(1,76)=21.36$	√
2M-An	$F(1,74)=.679$	$F(1,74)=40.78$	√
3M-A	$F(1,76)=3.81$	$F(1,76)=28.76$	√
4F-F	$F(1,76)=8.00$	$F(1,76)=7.42$	√
5F-T	$F(1,76)=1.54$	$F(1,76)=71.72$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different ΔB1 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(6,687)=44.12$; 1M-J $F(6,133) = 40.52$; 2M-An $F(6,131) = 36.26$; 3M-A $F(6,133) = 35.98$; 4F-F $F(6,133) = 21.39$; 5F-T $F(6,129) = 21.03$]. In every case, $p=0.000$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.59.

Table 4.59: Tuwuli ΔB1 Mean Values by Vowel Group for Each Speaker

Shaded cells within vowel groups indicate mean values which are not significantly different.

Vowel Group	Vowel Quality	Pooled Data	1M-J	2M-An	3M-A	4F-F	5F-T
i	i [+ATR]	5.2	-43.9	-9.7	-21.5	57.9	43.2
e	e [+ATR]	7.4	-24.2	12.3	-0.19	25.8	23.6
	ɛ [-ATR]	35.6	6.3	51.3	13.7	46.5	60.6
ɑ	ɑ [-ATR]	72.7	38.7	97.2	39.7	90.7	103
o	o [+ATR]	28.4	17.9	36.2	-4.9	53.2	39.9
	ɔ [-ATR]	61.9	14.7	86.9	24.9	93.2	89.7
u	u [+ATR]	32.9	17.7	25.5	-22.2	87.5	56

ΔB1 in Tuwuli is comparable to those of Dibole in which several of the mid-vowel [ATR] pairs fail to have statistically significantly different means. The model improves slightly when one-way ANOVA (with $\alpha = .01$) are run targeting the mid-vowel pairs only: The front mid vowels for speaker 4F-F no longer form a homogeneous subgroup while the front mid vowels for speaker 3M-A and the back mid vowels for speaker 1M-J continue to have ΔB1 means which are not statistically significantly different. Tuwuli ΔB1 is also comparable to Dibole ΔB1 in that the range of the absolute difference in ΔB1 for mid-vowel [ATR] pairs is moderate (21 – 50 Hz.)

4.4 Normalized A1-A2 (Spectral Flatness)

This section presents the results of the Normalized A1-A2 analysis for each of the eleven languages featured in this study. As presented in §3.3.5, Normalized A1-A2 is a measure of spectral flatness derived from subtracting the normalized relative intensity of the first to second formant of a vowel (Modeled A1-A2) from the observed relative intensity (Observed A1-A2). For each language, the following is presented:

- a graph displaying the mean Normalized A1-A2 values for each [ATR] harmony pair of the pooled data,
- the results of the ANOVA, and
- tables summarizing mean differences.

4.4.1 Foodo

The graph in Figure 4.75 displays the mean Normalized A1-A2 values for each of the Foodo vowel groups, revealing a tendency for [+ATR] mid vowels to have greater Normalized A1-A2 means than their [-ATR] counterparts. On the other hand, [+ATR] high vowels have either lower than or nearly the same means as their [-ATR] counterparts.

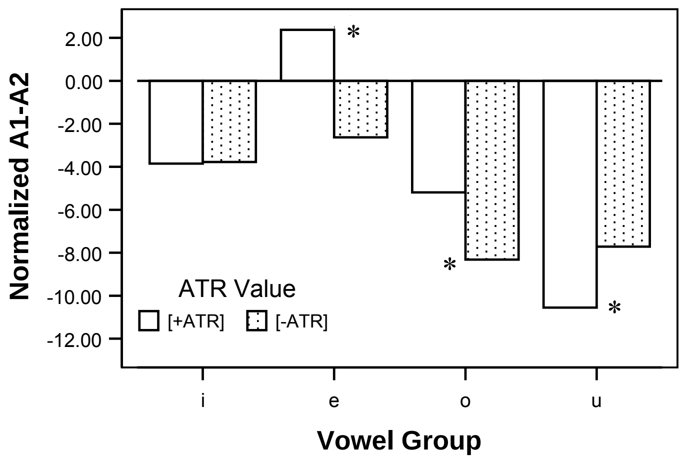

Figure 4.75: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the four Foodo speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Foodo speakers were submitted to a univariate ANOVA with the same three factors employed in §4.2.1: Vowel Group (/i ɪ/, /e ɛ/, /o ɔ/ and /u ʊ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that the main effect of [ATR] is significant [$F(1,624)=14.00$, p=0.000], as well as the three-way interaction between Vowel Group, [ATR] and Gender [$F(2,624)=6.48$, $p=0.000$]. These results suggest that the effect of [ATR] on the Normalized A1-A2 values differs by vowel type and by gender, but pattern differently in each combination of factors.

To further investigate Normalized A1-A2, four separate ANOVA, one for each speaker, were run (significance level set to 0.0125 for four comparisons) with [ATR] and Vowel Group as factors. The results are summarized in Table 4.60. Speakers 1M-K and 3F-B present similar results. In both cases, the main effects of Vowel Group and

[ATR] are significant with [+ATR] vowels having greater Normalized A1-A2 means than [-ATR] vowels. In the case of 1M-K, [ATR] does not interact significantly with Vowel Group, suggesting that the effect is more likely to be consistent across vowel groups. Speakers 2M-Z and 4F-Z also present similar results. In their case, the main effect of [ATR] is not significant. However, [ATR] interacts with Vowel Group indicating that the results are not consistent across vowel groups.

Table 4.60: Univariate ANOVA Results for Normalized A1-A2 in Foodo

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p < 0.0125$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-K	$F(3,152)=1.83$	$F(1,152)=6.25$	
2M-Z	$F(3,152)=16.23$	$F(1,152)=2.42$	
3F-B	$F(3,152)=3.91$	$F(1,152)=18.31$	√
4F-A	$F(3,152)=32.12$	$F(1,152)=672$	

In order to determine which vowel pairs in each speaker's data have significantly different Normalized A1-A2 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for all the vowels of each speaker. The main effect of Vowel Quality is significant for each speaker [1M-K $F(7,152) = 33.69$; 2M-Z $F(7,152) = 28.18$; 3F-B $F(7,152) = 16.14$; 4F-E $F(7,152) = 33.69$]. In every case, $p=0.000$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.61.

Table 4.61: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Foodo

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[i]-[ɪ]	[e]-[ɛ]	[o]-[ɔ]	[u]-[ʊ]
Pooled		√ [+ATR]	√ [+ATR]	√ [-ATR]
1M-K		√ [+ATR]		
2M-Z			√ [+ATR]	
3F-B		√ [+ATR]	√ [+ATR]	
4F-A		√ [+ATR]		√ [-ATR]

These results indicate that there is a greater tendency for mid vowels to have significantly different Normalized A1-A2 means; moreover, the [+ATR] vowel of the pair has the greater mean and thus steeper spectral slope. High vowels tend to not present significantly different means or, as is the case for the [u]-[ʊ] pair of speaker 4F-A, for the [-ATR] vowel to have the greater mean.

Due to their tendency to overlap in acoustic space, cross-height vowel pairs /ɪ e/ and /ʊ o/ were subjected to one-way ANOVA for each speaker as well as for the pooled data. These results are summarized in Table 4.62. In every case except for the /ʊ o/ pair of speaker 4F-A, the [-ATR] vowel of the pair has a significantly lower Normalized A1-A2 mean than the cross-height [+ATR] vowel, indicating a steeper spectral slope for the [+ATR] vowel.

Table 4.62: One-Way ANOVA Results of Normalized A1-A2 for Cross-Height Vowel Pairs in Foodo

Yellow highlighting indicates that the statistical significance goes the opposite direction from expectation: the [-ATR] vowel has a higher Normalized A1-A2 mean. In all cases, $p < .05$

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,158)$=85.59	$F(1,158)$=12.51
1M-K	$F(1,38)$= 6.41	$F(1,38)$=27.97
2M-Z	$F(1,38)$= 63.69	$F(1,38)$= 22.92
3F-B	$F(1,38)$= 4.95	$F(1,38)$= 22.84
4F-A	$F(1,38)$= 56.89	$F(1,38)$= 5.59

4.4.2 Ikposo

The graph in Figure 4.76 displays the mean Normalized A1-A2 values for each of the Ikposo vowel groups, revealing a tendency for [+ATR] mid vowels to have greater Normalized A1-A2 means than their [-ATR] counterparts. On the other hand, high vowels have mixed results: the [+ATR] back high vowels pattern like the mid vowels but the front high vowels have lower means than their [-ATR] counterparts. There is also a tendency for the [+ATR] low vowel to have lower means than the [-ATR] low vowel.

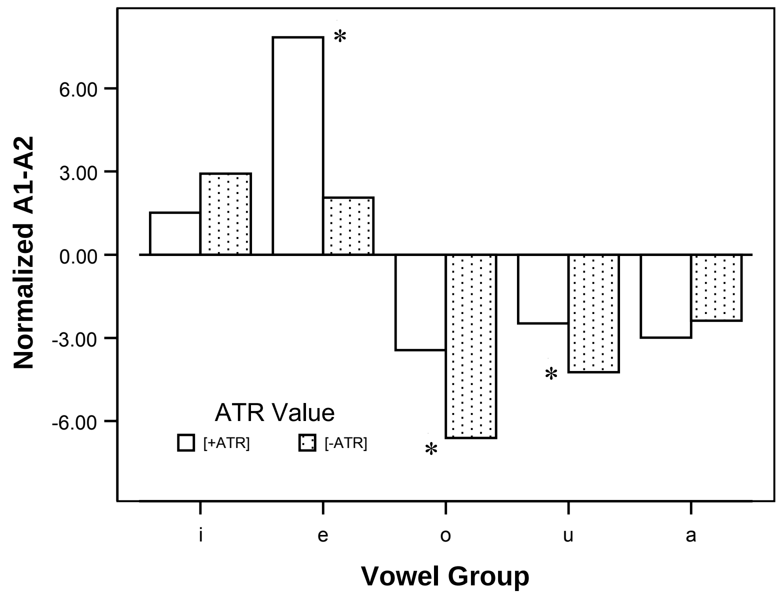

Figure 4.76: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five Ikposo speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Ikposo speakers were submitted to a univariate ANOVA with the same three factors: Vowel Group (/i ɪ/, /e ɛ/, /o ɔ/ /u ʊ/ and /ə ɑ/), [ATR] value ([+ATR] or [-ATR]), and Gender (male or female). The results indicate that the main effect of [ATR] is significant [$F(1,967)=39.29$, $p=0.000$], as well as the three-way interaction between Vowel Group, [ATR] and Gender [$F(4,967)=6.25$, $p=0.000$]. These results suggest that the effect of [ATR] on the Normalized A1-A2 values differs by vowel type and by gender, but pattern differently in each combination of factors.

To further investigate Normalized A1-A2, five separate ANOVA, one for each speaker, were run (significance level set to 0.01 for five comparisons) with [ATR] and

Vowel Group as factors (Table 4.63). Both females as well as male speaker 2M-J have similar results in that the main effect of [ATR] is significant. In the case of 5F-R, [ATR] does not interact with Vowel Group suggesting that the differences in [ATR] are consistent across vowel groups. For the remaining two male speakers, 1M-J and 3M-K, the main effect of [ATR] is not significant, but for 3M-K the effect is consistent across vowel groups. Speakers 2M-Z and 4F-Z also have similar results: in their case, the main effect of [ATR] is not significant, but [ATR] interacts with Vowel Group indicating that the results are not consistent across vowel groups.

Table 4.63: Univariate ANOVA Results for Normalized A1-A2 in Ikposo

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p \leq 0.001$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-J	$F(4,189)=35.38$	$F(1,189)=4.89$	
2M-Jo	$F(4,189)=17.76$	$F(1,189)=10.67$	√
3M-K	$F(4,189)=2.36$	$F(1,189)=5.19$	
4F-E	$F(4,190)=16.79$	$F(1,190)=51.94$	√
5F-R	$F(4,190)=3.23$	$F(1,190)=24.93$	√

In order to determine which vowel pairs in each speaker's data have significantly different Normalized A1-A2 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for all the vowels of each speaker. The main effect of Vowel Quality is significant for each speaker [1M-J $F(9,189) = 33.8$; 2M-Jo $F(9,189) = 24.09$; 3M-K $F(9,179) = 75.8$; 4F-E $F(9,190) = 41.45$; 5F-R $F(9,190) = 14.27$]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.64.

Table 4.64: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Ikposo

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[i]-[ɪ]	[e]-[ɛ]	[o]-[ɔ]	[u]-[ʊ]	[ə]-[ɑ]
Pooled		√ [+ATR]	√ [+ATR]		
1M-J	√ [-ATR]	√ [+ATR]			√ [-ATR]
2M-Jo	√ [-ATR]	√ [+ATR]	√ [+ATR]		√ [+ATR]
3F-K					
4F-E		√ [+ATR]	√ [+ATR]		
5F-R					

These results indicate that there is a greater tendency for the [+ATR] vowel of mid-vowel pairs to have a greater Normalized A1-A2 mean and thus steeper spectral slope. High vowels tend to not have statistically significant means or, in the case of the front pair for speakers 1M-J and 2M-Jo, to have greater means for the [-ATR] vowel of the pair. It is not surprising that the [-ATR] high front vowels for these two speakers have steeper spectral slopes than their [+ATR] counterparts given the bandwidth profiles for these speakers that we saw earlier in §4.3.2. Recall that while [i] was near the predicted bandwidth values, [ɪ] was well below predicted values for both of these speakers. Lastly, the low vowel pair tends to not have statistically significant Normalized A1-A2 means, but in the cases where it does, the results are mixed.

The pairs /ɪ e/ and /ʊ o/, which are close or overlap in acoustic space in Ikposo were also investigated. The results of one-way ANOVA conducted on the cross-height vowel pairs /ɪ e/ and /ʊ o/ for the pooled data (Table 4.65). Except in the case of 1M-H, the front cross-height pair tends to have statistically significant Normalized A1-A2 means, with the [+ATR] vowels of the pair having the higher mean. On the other hand, none of the back cross-height pairs have statistically significant Normalized A1-A2 means except for speaker 1M-J again. These results indicate overall a steeper spectral slope for the [+ATR] vowel for the front pair only.

Table 4.65: One-Way ANOVA Results of Normalized A1-A2 for Cross-Height Vowel Pairs in Ikposo

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p < 0.05$. In cells with statistically significant results, the [+ATR] vowel has a higher mean than the [-ATR] cross-height vowel.

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,196)=42.77$	$F(1,198)=4.58$
1M-J	$F(1,38)= .540$	$F(1,38)=6.83$
2M-Jo	$F(1,38)= 54.04$	$F(1,38)= 3.63$
3F-K	$F(1,37)= 10.97$	$F(1,38)= 1.08$
4F-E	$F(1,38)= 23.68$	$F(1,38)= .000$
5F-R	$F(1,38)= 6.29$	$F(1,38)= .17$

4.4.3 Kinande

In Figure 4.77 we see a graph of the mean Normalized A1-A2 values of each of the vowel groups for the pooled Kinande data. The graph reveals a tendency for the [+ATR] mid vowels only to have greater Normalized A1-A2 means than their [-ATR] counterparts. [+ATR] high vowels and low vowels have either lower than or nearly the same means as their [-ATR] counterparts.

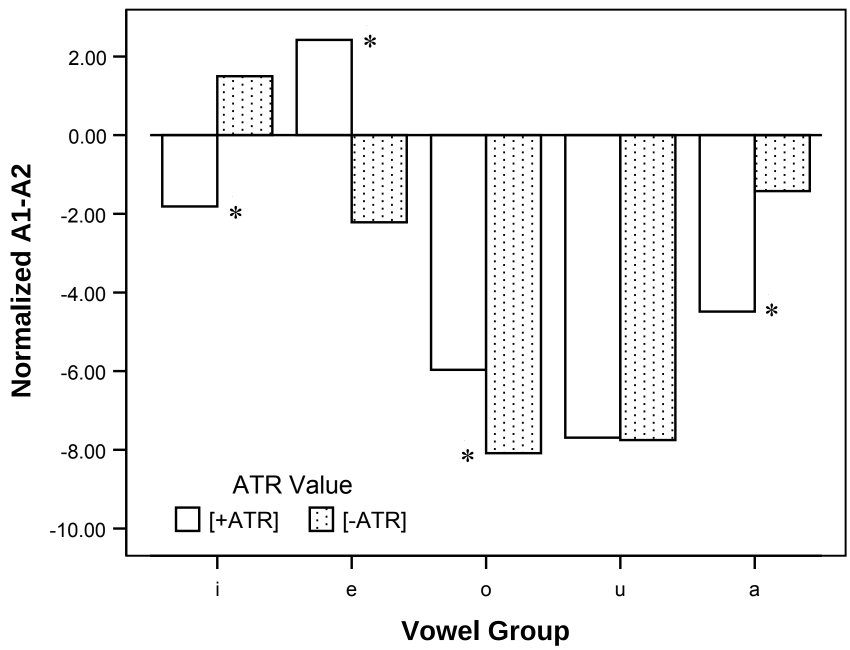

Figure 4.77: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the four Kinande speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the pooled Kinande data were submitted to a univariate ANOVA with the factors: Vowel Group (/i ɪ/, [e ɛ], [o ɔ], [ə ɑ] and /u ʊ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is just barely statistically significant: [$F(4,810)=2.39$, $p=0.05$]. The main effect of [ATR] is also significant [$F(1,810)=11.1$, $p=0.000$], with [+ATR] vowels having overall higher Normalized A1-A2 means than their [-ATR] counterparts. These results would indicate that though the effect of [ATR] on the Normalized A1-A2 values is statistically significant, it patterns differently depending on vowel type and gender.

Further investigation of Normalized A1-A2 includes four separate ANOVA, one for each speaker (significance level set to 0.0125 for four comparisons), with [ATR] and Vowel Group as factors (Table 4.66). [ATR] interacts significantly with Vowel Group in all four cases, but the main effect of [ATR] is significant only for speakers 1M-Kk and 4F-Jc. Of these two speakers, only the female speaker has [+ATR] vowels with higher Normalized A1-A2 means, indicating steeper spectral slopes. The inverse is true for speaker 1M-Kk. For the remaining two speakers, 2M-Ks and 3M-J, ATR and Vowel Group interact in such a way as to render the mean differences of their vowels non-significant.

Table 4.66: Univariate ANOVA Results for Normalized A1-A2 in Kinande

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p = 0.000$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-Kk	$F(4,190)=11.1$	$F(1,189)=22.18$	
2M-Ks	$F(4,200)=12.46$	$F(1,200)=1.32$	
3M-J	$F(4,200)=11.8$	$F(1,189)=5.59$	
4F-Jc	$F(4,200)=17.88$	$F(1,200)=49.35$	√

In order to determine which vowel pairs in each speaker's data have statistically significantly different Normalized A1-A2 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker [Pooled $F(9,820) = 46.47$; 1M-Kk $F(9,190) = 33.62$; 2M-Ks $F(9,200) = 24.27$; 3M-J $F(9,200) = 10.5$; 4F-Jc $F(9,200) = 70.3$]. In every case, *p*=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.67

Table 4.67: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Kinande

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[i]-[ɪ]	[e]-[ɛ]	[o]-[ɔ]	[u]-[ʊ]	[ə]-[ɑ]
Pooled	√ [-ATR]	√ [+ATR]			√ [-ATR]
1M-Kk	√ [-ATR]				
2M-Ks		√ [+ATR]	√ [+ATR]	√ [-ATR]	
3M-J	√ [-ATR]				√ [-ATR]
4F-Jc		√ [+ATR]	√ [+ATR]	√ [+ATR]	

The one-way ANOVA results largely confirm those indicated in the graph of Figure 4.77 for the univariate ANOVA: there is a tendency for vowel pairs to have significantly different Normalized A1-A2 means. However, as seen for speakers 2M-Ks and 4F-Jc, only in the case of mid vowels do the [+ATR] vowels have greater mean values and thus the steeper spectral slope. The other vowel pairs often present the reverse, with the [-ATR] vowel of the pair having the higher Normalized A1-A2 mean. As was indicated in the Post-Hoc results in Table 4.67, only female speaker 4F-Jc consistently produces [+ATR] vowels with statistically significantly higher Normalized A1-A2 means. The male speakers either have mixed results, (2M-Ks), or present significantly higher means among [-ATR] vowels (1M-Kk, 3M-J).

Cross-height pairs /ɪ e/ and /ʊ o/ which are close or overlapping in acoustic space, were also investigated using a one-way ANOVA (Table 4.68). Not surprisingly, 4F-Jc is the only speaker to have significantly higher Normalized A1-A2 means for the

[+ATR] vowel of both pairs. Among the males, the means of the front pair are not significantly different but the means of the back pair show mixed results. These results, along with the results for the [ATR] harmony vowel pairs, suggest that the [+ATR] vowels have consistently steeper slopes for the female speaker only.

Table 4.68: One-Way ANOVA Results of Normalized A1-A2 for
Cross-Height Vowel Pairs in Kinande

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p < 0.01$. Yellow highlighting indicates that the statistical significance goes the opposite direction from expectation: the [-ATR] vowel has a higher Normalized A1-A2 mean.

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,158)=.913$	$F(1,148)=8.38$
1M-Kk	$F(1,38)= .21$	$F(1,28)=8.2$
2M-Ks	$F(1,38)= .602$	$F(1,38)= 25.33$
3M-J	$F(1,38)= .535$	$F(1,38)= .144$
4F-Jc	$F(1,38)= 20.95$	$F(1,38)= 15.32$

4.4.4 LuBwisi

Figure 4.78 presents the graph of the mean Normalized A1-A2 values of each of the vowel groups for the pooled LuBwisi data. The graph suggests a tendency for all of the [+ATR] vowels to have greater Normalized A1-A2 means than their [-ATR] counterparts.

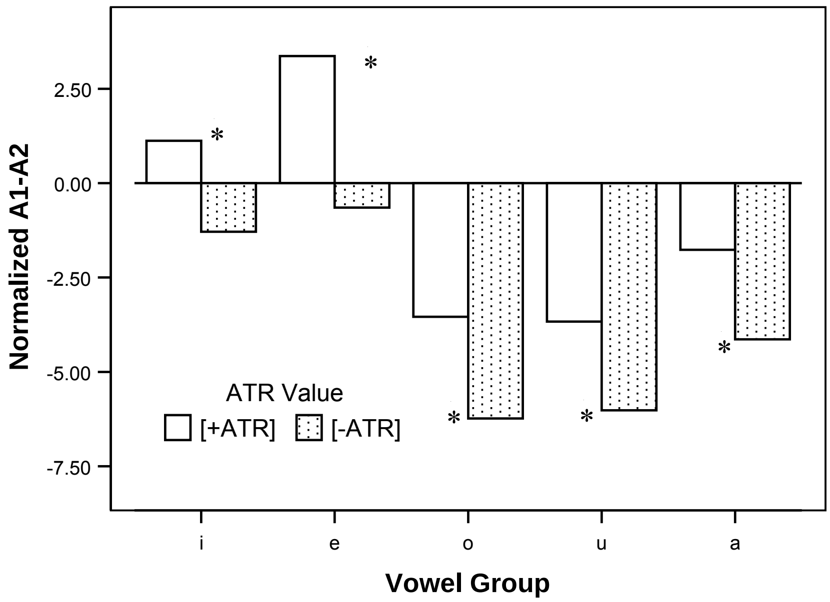

Figure 4.78: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five LuBwisi speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the pooled LuBwisi data were submitted to a univariate ANOVA with the factors: Vowel Group (/i ɪ/, [e ɛ], [o ɔ], [ə ɑ] and /u ʊ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is statistically significant: [$F(4,1128)=9.06$, $p=0.000$]. The main effect of [ATR] is also significant [$F(1,1128)=92.36$, $p=0.000$], with [+ATR] vowels having overall higher Normalized A1-A2 means than their [-ATR] counterparts. These results would indicate that though the effect of [ATR] on the Normalized A1-A2 values is statistically significant, it patterns differently among speakers depending on vowel type and gender.

Further investigation of Normalized A1-A2 included five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.69). The main effect of [ATR] is significant in all cases with [+ATR] vowels having higher Normalized A1-A2 means than their [-ATR] counterparts. With the exception of speaker 2M-H, [ATR] interacts significantly with Vowel indicating that the effect is not consistent across vowel pairs for most speakers.

Table 4.69: Univariate ANOVA Results for Normalized A1-A2 in LuBwisi

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p \leq 0.001$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-B	$F(4,220)=10.4$	$F(1,220)=38.71$	√
2M-H	$F(4,220)=1.85$	$F(1,220)=56.19$	√
3M-W	$F(4,220)=8.39$	$F(1,220)=50.1$	√
4F-T	$F(4,218)=5.0$	$F(1,218)=40.09$	√
5F-Z	$F(4,220)=23.2$	$F(1,220)=12.18$	√

For a clearer idea of which vowel pairs in each speaker's data have statistically significant Normalized A1-A2 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled data. The main effect of Vowel Quality is significant for each speaker [Pooled $F(9,1138) = 46.21$; 1M-B $F(9,220) = 22.87$; 2M-H $F(9,220) = 28.83$; 3M-W $F(9,220) = 45.48$; 4F-T $F(9,218) = 37.15$; 5F-Z $F(9,220) = 15.59$]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.70

Table 4.70: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in LuBwisi

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[i]-[ɪ]	[e]-[ɛ]	[o]-[ɔ]	[u]-[ʊ]	[ə]-[ɑ]
Pooled	√ [+ATR]	√ [+ATR]	√ [+ATR]	√ [+ATR]	√ [+ATR]
1M-B		√ [+ATR]	√ [+ATR]	√ [+ATR]	√ [+ATR]
2M-H				√ [+ATR]	√ [+ATR]
3F-W	√ [+ATR]			√ [+ATR]	
4F-T		√ [+ATR]			
5F-Z	√ [+ATR]	√ [+ATR]	√ [+ATR]	√ [-ATR]	

The one-way ANOVA results confirm those indicated in the graph of Figure 4.78 for the univariate ANOVA: the tendency for vowel pairs to have significantly different Normalized A1-A2 means is reflected among individual speakers. In addition, the [+ATR] vowel of the pairs consistently has the greater mean, and thus steeper spectral slope. The only exception occurs among the vowel pairs for speaker 5F-Z, where the [-ATR] high back vowel has a higher Normalized A1-A2 mean.

Cross-height pairs [ɪ e] and [ʊ o] which are close or overlapping in acoustic space, were also subjected to a one-way ANOVA (Table 4.71). In seven of ten cases, the vowel pairs have significantly different Normalized A1-A2 means, with the [+ATR] vowel of the pair having the higher mean. These results, along with the results for the [ATR] harmony vowel pairs, suggest that the [+ATR] vowels have consistently steeper spectral slopes.

Table 4.71: One-Way ANOVA Results of Normalized A1-A2 for Cross-Height Vowel Pairs in LuBwisi

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p < 0.01$. In cells with statistically significant results, the [+ATR] vowel has a higher mean than the [-ATR] cross-height vowel.

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,198)=35.17$	$F(1,148)=21.41$
1M-B	$F(1,38)= 18.18$	$F(1,48)=23.26$
2M-H	$F(1,38)= .265$	$F(1,48)= 21.95$
3F-W	$F(1,38)= 52.16$	$F(1,48)= 7.80$
4F-T	$F(1,38)= 8.3$	$F(1,48)= 3.13$
5F-Z	$F(1,38)= 30.37$	$F(1,48)= 1.05$

4.4.5 Ekiti-Yoruba

Figure 4.79 presents the graph of the mean Normalized A1-A2 values of each of the vowel groups for the pooled Ekiti-Yoruba data.[50] The graph suggests a tendency for mid [+ATR] vowels and high front [+ATR] to have greater Normalized A1-A2 means than their [-ATR] counterparts.

[50] Unless otherwise indicated, the data for the Moba speaker are not included in these results.

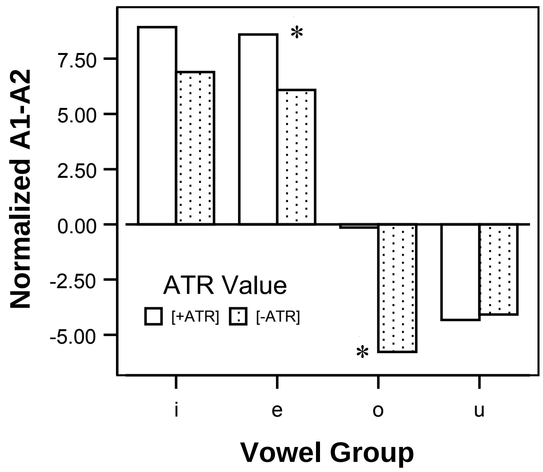

Figure 4.79: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the three Ekiti speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the pooled Ekiti data (three speakers) were submitted to a univariate ANOVA with the factors: Vowel Group ([i ɪ], /e ɛ/, /o ɔ/ and [u ʊ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). Neither the three-way interaction between Vowel Group, [ATR] and Gender nor the two-way interaction of [ATR] and Gender are statistically significant: [$F(3,462)=1.54$; $F(1,462)=.340$]. However, the two-way interaction of [ATR] and Vowel Group as well as the main effect of [ATR] are both significant [$F(1,462)=6.77$; $F(1,462)=32.21$, both with $p=0.000$]. [+ATR] vowels have greater Normalized A1-A2 means than their [-ATR] counterparts, but the effect is not consistent across vowel pairs.

Further investigation of Normalized A1-A2 included three separate ANOVA, one for each speaker (significance level set to 0.0167 for three comparisons), with

[ATR] and Vowel Group as factors. The results are summarized in Table 4.72. The main effect of [ATR] is significant in two cases, 1M-A and 3F-F with [+ATR] vowels having higher Normalized A1-A2 means than their [-ATR] counterparts. [ATR] interacts significantly with Vowel Group for the two male speakers but in such a way for speaker 2M-M that the differences in mean values for his vowel pairs are not significant. The effect of [ATR] is consistent across vowel pairs for the female speaker.

Table 4.72: Univariate ANOVA Results for Normalized A1-A2 in Ekiti

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p < 0.01$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-A	$F(3,152)=3.98$	$F(1,152)=28.47$	√
2M-M	$F(3,150)=15.36$	$F(1,150)=3.39$	
3F-F	$F(3,152)=2.82$	$F(1,152)=18.24$	√

For a clearer idea of which vowel pairs in each speaker's data have statistically significant Normalized A1-A2 means, one-way ANOVA with Vowel Quality as the independent factor were also conducted for the [ATR] harmony vowel pairs of each speaker as well as for the pooled Ekiti data. An ANOVA was also run for the one Mọba speaker for comparison. The main effect of Vowel Quality is significant for each speaker as well as the pooled data: [Pooled $F(7,470) = 108.42$; 1M-A $F(7,152) = 24.44$; 2M-M $F(7,150) = 49.88$; 3F-F $F(7,152) = 125.6$; 4F-N $F(7,152) = 59.87$]. In every case, $p=0.000$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.73.

Table 4.73: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Ekiti

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[i]-[ɪ]	[e]-[ɛ]	[o]-[ɔ]	[u]-[ʊ]
Pooled Ekiti			√ [+ATR]	
1M-A			√ [+ATR]	
2M-M		√ [+ATR]		
3F-F			√ [+ATR]	
4F-N (Mọba)				

The one-way ANOVA confirm that only mid-vowels have statistically significant Normalized A1-A2 means: the [+ATR] vowel of the pairs presents the greater value. Note that only one pair for each speaker has significantly different means. In contrast with the Ekiti data, the Mọba speaker has no vowel pairs which may be distinguished by Normalized A1-A2 means.

Cross-height pairs [ɪ e] and [ʊ o], which are close or overlapping in acoustic space, were also investigated for the three Ekiti speakers and the result of the one-way ANOVA conducted are summarized in Table 4.74. Only the female speaker has vowel pairs with significantly different Normalized A1-A2 means. In both pairs, the [+ATR] vowel has the higher mean. These results suggest a tendency among Ekiti speakers for [+ATR] mid vowels to have consistently steeper spectral slopes. This is most apparent in the data of the female speaker whose [+ATR] mid vowels also have higher Normalized A1-A2 means than their cross-height [-ATR] vowel pair.

Table 4.74: One-Way ANOVA Results of Normalized A1-A2 for Cross-Height Vowel Pairs in Ekiti

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p \leq 0.002$. In cells with statistically significant results, the [+ATR] vowel has a higher mean than the [-ATR] cross-height vowel.

Speaker	Vowel Pair: ɪ e	Vowel Pair: ʊ o
Pooled Data	$F(1,117)=3.82$	$F(1,117)=18.47$
1M-A	$F(1,38)= .000$	$F(1,38)=3.7$
2M-M	$F(1,37)= .965$	$F(1,38)= .019$
3F-F	$F(1,38)= 11.54$	$F(1,38)= 38.92$

4.4.6 Ifè

Figure 4.80 presents the graph of the mean Normalized A1-A2 values of the two [ATR] harmony vowel pairs for the pooled Ifè data. The graph suggests a tendency for the [+ATR] vowels to have greater Normalized A1-A2 means than their [-ATR] counterparts.

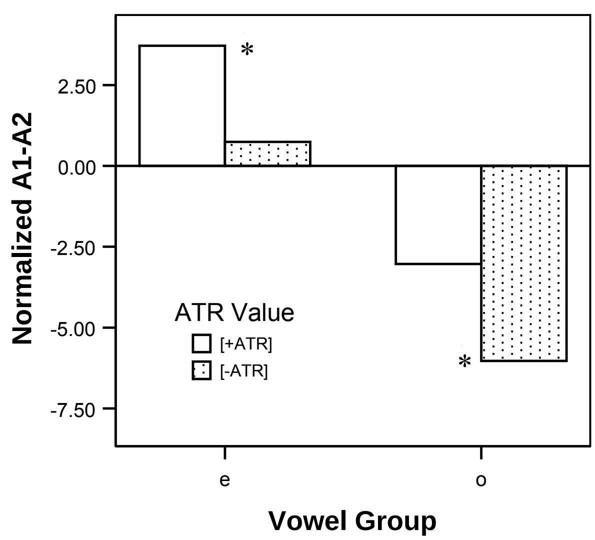

Figure 4.80: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five Ifè speakers. Significant differences in [ATR] for a given vowel

group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Ifè speakers were submitted to a univariate ANOVA with three factors: Vowel Group ([e ɛ] and [o ɔ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is statistically significant: [$F(1,399)=7.58$, $p=0.006$]. The main effect of [ATR] is significant [$F(1,399)=60.98$, $p=0.000$] with [+ATR] vowels having greater Normalized A1-A2 means than their [-ATR] counterparts. The effect, however, is not consistent across vowel pairs or gender.

Further investigation of Normalized A1-A2 included five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.75). [ATR] interacts significantly with Vowel Group for only speaker 4F-I. In the four cases where it does not interact significantly with Vowel Group, the main effect of [ATR] is not significant for speaker 1M-Kv. For the other male speakers, as well as female speaker 5F-M, the main effect of [ATR] is consistent across the vowel pairs. For the remaining female, 4F-I, the main effect of [ATR] is significant but not consistent across the vowel pairs. For all four speakers with significant results for [ATR], the [+ATR] vowel has the greater Normalized A1-A2 mean, and thus steeper spectral slope.

Table 4.75: Univariate ANOVA Results for Normalized A1-A2 in Ifè

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p < 0.01$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-Kv	$F(1,70)=.179$	$F(1,70)=.074$	
2M-Y	$F(1,70)=.43$	$F(1,70)=40.1$	√
3M-K	$F(1,73)=3.22$	$F(1,73)=7.96$	√
4F-I	$F(1,73)=9.63$	$F(1,73)=61.34$	√
5F-M	$F(1,78)=2.28$	$F(1,78)=23.19$	√

One-way ANOVA with Vowel Quality as the independent factor were also conducted for further study of the Normalized A1-A2 differences in vowel pairs. ANOVA were run for each speaker (significance level set to 0.01 for five speakers) as well as for the pooled data. The main effect of Vowel Quality is significant in all cases: [Pooled $F(3,403) = 109.59$; 1M-Kv $F(3,70) = 66.86$; 2M-Y $F(3,93) = 36.96$; 3M-K $F(3,73) = 7.81$; 4F-I $F(3,73) = 46.82$; 5F-M $F(3,78) = 45.4$]. In every case, p=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.76.

Table 4.76: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Ifè

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[e]-[ɛ]	[o]-[ɔ]
Pooled	√ [+ATR]	√ [+ATR]
1M-Kv		
2M-Y	√ [+ATR]	√ [+ATR]
3M-K		√ [+ATR]
4F-I	√ [+ATR]	√ [+ATR]
5F-M	√ [+ATR]	

The one-way ANOVA support the results of the univariate ANOVA analysis: neither vowel pair for 1M-Kv has statistically significantly different Normalized A1-A2 means. For speakers 2M-Y and 4F-I, both pairs have significantly different means, while speakers 3M-K and 5F-M have one pair each presenting different means. In every case where means are significant, the [+ATR] vowel has the higher mean indicating a steeper spectral slope. The effect is consistent across the data.

4.4.7 Dibole

Figure 4.81 presents the graph of the mean Normalized A1-A2 values of the two [ATR] harmony vowel pairs for the pooled Dibole data. The graph suggests that the [+ATR] vowels have a somewhat greater Normalized A1-A2 mean than their [-ATR] counterparts.

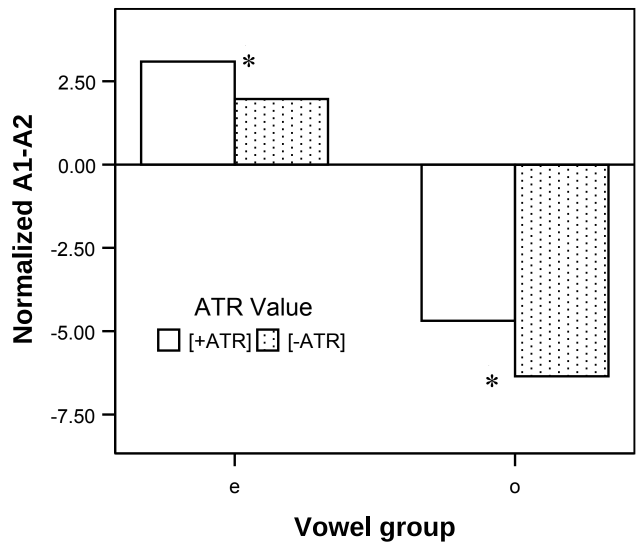

Figure 4.81: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five Dibole speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Dibole speakers were submitted to a univariate ANOVA with three factors: Vowel Group ([e ɛ] and [o ɔ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is not statistically significant: [$F(1,392)=3.58$,]. Neither are the two-way interactions of [ATR] and Gender nor ATR and Vowel Group [$F(1,392)=3.74$; $F(1,392)=.133$]. The main effect of [ATR], however, is significant [$F(1,392)=17.75$, $p=0.000$] with [+ATR] vowels having greater Normalized A1-A2 means than their [-ATR] counterparts. The effect is consistent across vowel pairs and across gender.

Further investigation of Normalized A1-A2 included five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors (Table 4.77). As anticipated, [ATR] does not interact with Vowel Group except for one speaker, 3F-S. Contrary to the expectations of the pooled univariate, the main effect of [ATR] is not significant for any of the female speakers. It is significant for the two male speakers and is consistent across vowel pairs. For those two cases, the [+ATR] vowels have higher Normalized A1-A2 means than their [-ATR] counterparts.

Table 4.77: Univariate ANOVA Results for Normalized A1-A2 in Dibole

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p < 0.01$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1F-MN	$F(1,76)=.210$	$F(1,76)=.005$	
2F-F	$F(1,76)=.214$	$F(1,76)=6.26$	
3F-S	$F(1,76)=11.16$	$F(1,76)=.791$	
4M-C	$F(1,76)=2.79$	$F(1,76)=15.5$	√
5M-L	$F(1,76)=.006$	$F(1,78)=7.49$	√

One-way ANOVA with Vowel Quality as the independent factor were also conducted for further study of the Normalized A1-A2 differences in vowel pairs. ANOVA were run for each speaker (significance level set to 0.01 for five speakers) as well as for the pooled data. The main effect of Vowel Quality is significant in all cases: [Pooled $F(3,396) = 117.32$; 1F-MN $F(3,76) = 60.67$; 2F-F $F(3,76) = 100.59$; 3F-S $F(3,76) = 25.25$; 4M-C $F(3,76) = 12.74$; 5M-L $F(3,76) = 62.72$]. In every case, *p*=0.000. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.78.

Table 4.78: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Dibole

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[e]-[ɛ]	[o]-[ɔ]
Pooled		√ [+ATR]
1F-MN		
2F-F		
3F-S		
4M-C	√ [+ATR]	
5M-L		

The one-way ANOVA support the results of the univariate ANOVA analysis but fail to differentiate either vowel pairs for speaker 5M-L ($p > 0.05$). Neither vowel pair for 1M-Kv presents statistically significant differences for Normalized A1-A2 means. Overall, Normalized A1-A2 is not a robust measurement of [ATR] differences for these Dibole data.

4.4.8 Mbosi

Figure 4.82 presents the graph of the mean Normalized A1-A2 values of the two [ATR] harmony vowel pairs for the pooled Mbosi data. The graph has a similar profile as that for Dibole, in that the [+ATR] vowels have a somewhat greater Normalized A1-A2 mean than their [-ATR] counterparts. The differences, however, appear to be more robust.

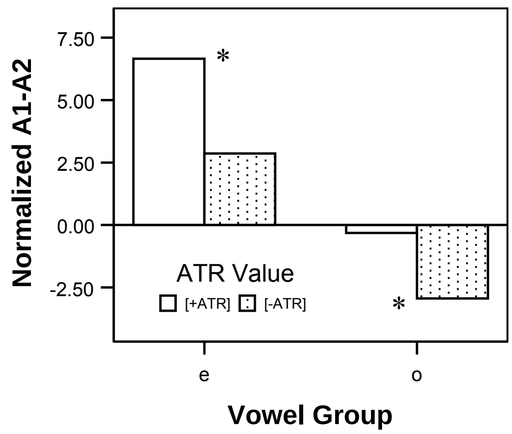

Figure 4.82: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five Mbosi speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Mbosi speakers were submitted to a univariate ANOVA with three factors: Vowel Group ([e ɛ] and [o ɔ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is not statistically significant: [$F(1,372)=2.9$]. Neither is the two-way interaction of [ATR] and Gender [$F(1,372)=4.72$]. ATR and Vowel Group, however, interact significantly: [$F(1,372)=22.06$ $p=0.000$]. The main effect of [ATR] is also significant [$F(1,372)=75.86$, $p=0.000$] with [+ATR] vowels having greater Normalized A1-A2 means than their [-ATR] counterparts. However, the effect is not consistent across vowel pairs.

Further investigation of Normalized A1-A2 included five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and

Vowel Group as factors. Results are summarized in Table 4.79. As anticipated, [ATR] does interact with Vowel Group in some of the cases: 2M-Le and 5F-M. In the case of the latter speaker, the main effect of [ATR] is not significant. The main effect of [ATR] is not significant for 3M-O and this is consistent across his vowel pairs. For the three speakers whose main effect of [ATR] is significant, the [+ATR] vowels have higher Normalized A1-A2 means than their [-ATR] counterparts.

Table 4.79: Univariate ANOVA Results for Normalized A1-A2 in Mbosi

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p \leq 0.002$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-C	$F(1,66)=3.26$	$F(1,66)=10.75$	√
2M-Le	$F(1,76)=11.62$	$F(1,76)=36.37$	√
3M-O	$F(1,66)=5.32$	$F(1,66)=.821$	
4F-Ly	$F(1,76)=4.17$	$F(1,73)=107.85$	√
5F-M	$F(1,76)=16.16$	$F(1,76)=5.14$	

One-way ANOVA with Vowel Quality as the independent factor were also conducted for further study of the Normalized A1-A2 differences in vowel pairs. ANOVA were run for each speaker (significance level set to 0.01 for five speakers) as well as for the pooled data. The main effect of Vowel Quality is significant in all cases: [Pooled $F(3,376) = 86.27$; 1M-C $F(3,66) = 69.95$; 2M-Le $F(3,76) = 37.38$; 3M-O $F(3,66) = 4.64$; 4F-Ly $F(3,76) = 47.01$; 5F-M $F(3,76) = 17.32$]. In every case, $p \leq 0.005$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.80.

Table 4.80: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Mbosi

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[e]-[ɛ]	[o]-[ɔ]
Pooled	√ [+ATR]	
1M-C		√ [+ATR]
2M-Le	√ [+ATR]	
3M-O		
4F-Ly	√ [+ATR]	√ [+ATR]
5F-M	√ [+ATR]	

As anticipated, the results for Mbosi are much more robust than those for Dibole. With the exception of 3M-O, every speaker has at least one vowel pair with significantly different Normalized A1-A2 means. In the case of female speaker, 4F-Ly, both vowel pairs have statistically significantly different means. In every case where the Normalized A1-A2 means are significantly different, the [+ATR] vowel has the greater value, indicating a steeper spectral slope.

4.4.9 Mbonge

Figure 4.83 presents the graph of the mean Normalized A1-A2 values of the two [ATR] harmony vowel pairs for the pooled Mbonge data. As seen in the other 7-vowel languages so far, [+ATR] vowels appear to have higher Normalized A1-A2 means than their [-ATR] counterparts.

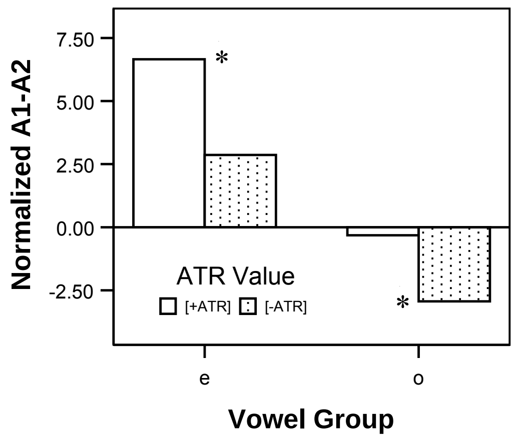

Figure 4.83: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five Mbonge speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Mbonge speakers were submitted to a univariate ANOVA with three factors: Vowel Group ([e ɛ] and [o ɔ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is not statistically significant: [$F(1,404)=.028$]. [ATR] also does not interact significantly with Vowel Group in the two-way interaction [$F(1,404)=.115$] but does interact significantly with Gender [$F(1,404)=6.72$, $p=0.010$]. The main effect of [ATR] is also significant [$F(1,404)=77.61$, $p=0.000$] with [+ATR] vowels having greater Normalized A1-A2 means than their [-ATR] counterparts. The effect is therefore consistent across vowel pairs but not across gender.

Further investigation of Normalized A1-A2 included five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and

Vowel Group as factors (Table 4.81). As anticipated, [ATR] does not interact with Vowel Group for any of the speakers. For two of the speakers, 2M-J and 5F-B, the main effect of [ATR] is not significant. For the remainder, the main effect of [ATR] is significant with the [+ATR] vowels having higher Normalized A1-A2 means than their [-ATR] counterparts.

Table 4.81: Univariate ANOVA Results for Normalized A1-A2 in Mbonge

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p = 0.000$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-Jo	$F(1,82)=.382$	$F(1,82)=20.36$	√
2M-J	$F(1,79)=.775$	$F(1,76)=3.5$	
3M-P	$F(1,78)=.055$	$F(1,78)=13.21$	√
4F-J	$F(1,78)=.452$	$F(1,78)=82.44$	√
5F-B	$F(1,76)=1.07$	$F(1,76)=4.94$	

One-way ANOVA with Vowel Quality as the independent factor were also conducted for further study of the Normalized A1-A2 differences in vowel pairs. ANOVA were run for each speaker (significance level set to 0.01 for five speakers) as well as for the pooled data. The main effect of Vowel Quality is significant in all cases: [Pooled $F(3,396) = 117.32$; 1M-Jo $F(3,82) = 47.08$; 2M-J $F(3,79) = 4.11$; 3M-P $F(3,78) = 42.44$; 4F-J $F(3,78) = 70.48$; 5F-B $F(3,75) = 18.83$]. In every case, $p<0.01$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.82.

Table 4.82: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Mbonge

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[e]-[ɛ]	[o]-[ɔ]
Pooled	√ [+ATR]	√ [+ATR]
1M-Jo	√ [+ATR]	
2M-J		
3M-P		
4F-J	√ [+ATR]	√ [+ATR]
5F-B		

The one-way ANOVA support the results of the univariate ANOVA analysis but fail to differentiate either vowel pairs for speaker 3M-P. As predicted by the univariate model, the vowels for speakers 2M-J and 5F-B do not have significantly different means. Overall, while there is a tendency in Mbonge for [+ATR] mid vowels to have higher spectral means than their [-ATR] counterparts, it is not robust across speakers.

4.4.10 Londo

Figure 4.84 presents the graph of the mean Normalized A1-A2 values of the two [ATR] harmony vowel pairs for the pooled Londo data.[51] Unlike Mbonge or any of the other 7-vowel languages observed thus far, Londo mid vowel pairs appear to have [-ATR] vowels with higher Normalized A1-A2 means than their [+ATR] counterparts. Contrary to what is predicted, this would indicate a tendency for the [-ATR] vowels to have steeper spectral slopes than [+ATR] vowels.

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[51] The data for speaker 1M-CE proved unsuitable to harmonic differential analysis and thus are not included in these results.

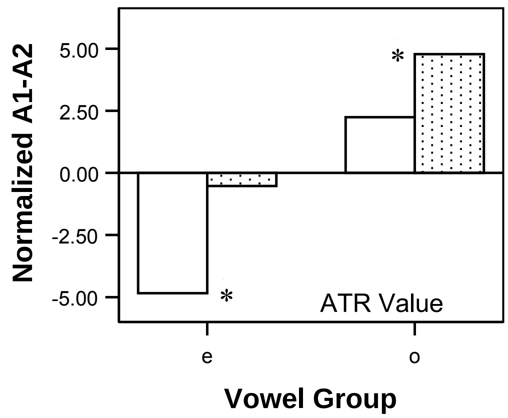


Figure 4.84: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five Londo speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Londo speakers were submitted to a univariate ANOVA with the factors: Vowel Group ([e ɛ] and [o ɔ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is not statistically significant: [$F(1,306)=.512$]. Neither is the two-way interaction of [ATR] and Vowel Group [$F(1,306)=2.61$]. ATR and Gender, however, interact significantly: [$F(1,306)=38.22$ $p=0.000$]. The main effect of [ATR] is also significant [$F(1,306)=29.92$, $p=0.000$] with [-ATR] vowels having greater Normalized A1-A2 means than their [+ATR] counterparts. The effect is not consistent across gender.

Further investigation of Normalized A1-A2 included four separate ANOVA, one for each speaker (significance level set to 0.0125 for four comparisons), with [ATR] and Vowel Group as factors (Table 4.83). As anticipated, [ATR] does not interact with

Vowel Group in most cases; 5F-H is the only exception. In the case of the latter speaker, the main effect of [ATR] is not significant. The main effect of [ATR] is significant for all four speakers, but only one, 2M-W has [+ATR] vowels with greater Normalized A1-A2 means. The other speakers all have [-ATR] vowels with greater Normalized A1-A2 means than their [+ATR] counterparts.

Table 4.83: Univariate ANOVA Results for Normalized A1-A2 in Londo

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p \leq 0.0125$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
2M-W	*F*(1,72)=2.65	*F*(1,72)=9.69	√
3M-I	*F*(1,74)=.096	*F*(1,78)=6.63	
4F-M	*F*(1,76)=.198	*F*(1,76)=58.53	
5F-H	*F*(1,76)=9.22	*F*(1,76)=86.13	

One-way ANOVA with Vowel Quality as the independent factor were also conducted for further study of the Normalized A1-A2 differences in vowel pairs. ANOVA were run for each speaker (significance level set to 0.0125 for four speakers) as well as for the pooled data. The main effect of Vowel Quality is significant in all cases: [Pooled $F(3,310) = 31.31$; 2M-W $F(3,72) = 4.31$; 3M-I $F(3,74) = 14.83$; 4F-M $F(3,76) = 140.52$; 5F-H $F(3,76) = 38.76$]. In every case, $p<0.01$. The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.84.

Table 4.84: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Londo

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[e]-[ɛ]	[o]-[ɔ]
Pooled	√ [-ATR]	
2M-W		√ [+ATR]
3M-I		
4F-M	√ [-ATR]	√ [-ATR]
5F-H	√ [-ATR]	√ [-ATR]

The results of the one-way ANOVA confirm that [-ATR] mid vowels have higher Normalized A1-A2 means than their [+ATR] counterparts. This effect is most noticeable among the female speakers, as the one-way ANOVA model does not differentiate between [ATR] harmony pairs either at a significance level set to 0.0125 or 0.05 for speaker 3M-I as it did in the univariate model.

4.4.11 Tuwuli

Figure 4.85 presents the graph of the mean Normalized A1-A2 values of the two [ATR] harmony vowel pairs for the pooled Tuwuli data. Like Londo, Tuwuli mid-vowel pairs appear to have [-ATR] vowels with higher Normalized A1-A2 means than their [+ATR] counterparts.

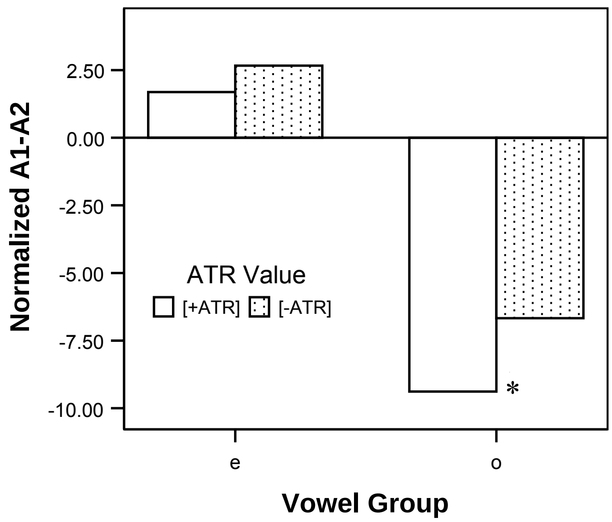


Figure 4.85: Mean values for the normalized relative intensity of the first to the second formant calculated by subtracting the Modeled A1-A2 values from the Observed A1-A2 values for the five Tuwuli speakers. Significant differences in [ATR] for a given vowel group are marked with an asterisk. A greater value indicates relatively greater spectral slopes for the observed than the modeled value.

The Normalized A1-A2 values for the [ATR] harmony vowel pairs for the Tuwuli speakers were submitted to a univariate ANOVA with three factors: Vowel Group ([e ɛ] and [o ɔ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). The three-way interaction between Vowel Group, [ATR] and Gender is not statistically significant: [$F(1,390)=1.75$]. However, both ATR and Gender and [ATR] and Vowel Group have significant interactions in the two-way factoral analysis [$F(1,390)=6.41$, $p=.012$; $F(1,390)=5.9$, $p=.016$]. The main effect of [ATR] is also significant [$F(1,390)=25.86$, $p=0.000$] with [-ATR] vowels having greater Normalized A1-A2 means than their [+ATR] counterparts. The effect is not consistent across gender or across vowel group.

Further investigation of Normalized A1-A2 included five separate ANOVA, one for each speaker (significance level set to 0.01 for five comparisons), with [ATR] and Vowel Group as factors. Results are summarized in Table 4.85. As might be expected from the pooled univariate, [ATR] does interact with Vowel Group in several cases. However, in only one case, that of speaker 4F-F, is the main effect of [ATR] significant. And in her case, [-ATR] vowels have greater Normalized A1-A2 means than their [+ATR] counterparts. It would seem that Normalized A1-A2 is not a robust measure for [ATR] harmony pairs in Tuwuli.

Table 4.85: Univariate ANOVA Results for Normalized A1-A2 in Tuwuli

Shaded cells indicate mean differences are not significant. Where Normalized A1-A2 means are significantly different, $p \leq 0.003$. A check indicates that the Normalized A1-A2 mean for the [+ATR] vowel is greater than the mean for its [-ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[+ATR] Greater
1M-J	$F(1,76)=15.79$	$F(1,76)=2.55$	
2M-An	$F(1,74)=5.92$	$F(1,74)=4.2$	
3M-A	$F(1,76)=11.04$	$F(1,76)=1.01$	
4F-F	$F(1,76)=9.72$	$F(1,76)=78.31$	
5F-T	$F(1,76)=4.43$	$F(1,76)=2.92$	

One-way ANOVA with Vowel Quality as the independent factor were also conducted for further study of the Normalized A1-A2 differences in vowel pairs. ANOVA were run for each speaker (significance level set to 0.01 for five speakers) as well as for the pooled data. The main effect of Vowel Quality is significant in all cases: [Pooled $F(3,394) = 178.67$; 1M-J $F(3,76) = 76.29$; 2M-An $F(3,74) = 54.65$; 3M-A $F(3,76) = 31.63$; 4F-F $F(3,76) = 133.6$; 5F-T $F(3,76) = 290.04$]. In every case, p=0.000.

The results of the pairwise comparisons as determined by a Tukey Post-Hoc test are summarized in Table 4.86.

Table 4.86: One-Way ANOVA Results of Normalized A1-A2 for [ATR] harmony Vowel Pairs in Tuwuli

A check mark indicates that the [ATR] feature indicated has a greater Normalized A1-A2 mean than its counterpart.

	[e]-[ɛ]	[o]-[ɔ]
Pooled		√ [-ATR]
1M-J		√ [-ATR]
2M-An		
3M-A		
4F-F	√ [-ATR]	√ [-ATR]
5F-T		

The results of the one-way ANOVA largely confirm that Normalized A1-A2 plays little role in distinguishing [ATR] harmony pairs. But when the mean differences are significant, the [-ATR] mid vowels have higher Normalized A1-A2 means than their [+ATR] counterparts. Again, as it was in the Londo data, this effect is most noticeable among a female speaker (4F-F).

4.5 Center of Gravity

This section presents the results of the center of gravity analysis for each of the eleven languages featured in this study. For each language, the following is presented:

- the results of the ANOVA
- a table summarizing the ANOVA results for center of gravity, F1, and the center of gravity – F1 differential, and
- a table of paired t-tests for the center of gravity – F1 differential.

4.5.1 Foodo

The center of gravity values of the [ATR] harmony pairs were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, /e ɛ/, /u ʊ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group [$F(3,620)=2.93$, $p=.033$]. The main effect of [ATR] is also significant [$F(1,620)=627.85$, $p=.000$] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across gender and vowel group.

Four separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.0125 for four comparisons) with Vowel Group and [ATR] value as factors (Table 4.87). [ATR] interacts significantly with Vowel Group for two of the speakers, 2M-Z and 4F-A, but not with the other two speakers, 1M-K and 3F-B. The main effect of [ATR], however, is significant at $p=0.000$ for all four speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.87: Univariate ANOVA Results for Center of Gravity in Foodo

Shaded cells indicate mean values which are not significant. Where center of gravity means are significantly different, $p<0.01$. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-K	$F(3,152)=2.56$	$F(1,152)= 330.2$	√
2M-Z	$F(3,152)=5.1$	$F(1,152)= 181.6$	√
3F-B	$F(3,152)=1.49$	$F(1,152)=120$	√
4F-A	$F(3,148)=15.84$	$F(1,148)= 291.78$	√

To further investigate center of gravity within the Foodo vowel system, the center of gravity values of all the vowels of each Foodo speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.0125 for four speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.88, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.1 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.88: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Foodo

Shaded cells indicate mean differences that are not significant – yellow for center of gravity and gray for F1. Diagonal lines indicate cross-height vowels. Superscript numbers indicate which cross-height vowels have means that are not significant. Red lettering indicates a reversed order for cross-height vowels.

Speaker	Vowel	i	ɪ	e	ɛ	ɑ	ɔ	o	ʊ	u
Pooled Data	CoG	573	784	602	866	1067	782	579[1]	549[1]	366
	F1	328	477[1]	493[1]	671	894	697	523[2]	493[2]	360
	CoG-F1	245	307	109	195	173	85	56	56	6
1M-K	CoG	524	717[1]	643[1]	926	1015	759	548[2]	587[2]	371
	F1	330	458[1]	457[1]	705	898	662	485[2]	503[2]	375
	CoG-F1	194	259	185	221	117	97	63	84	-4
2M-Z	CoG	525	636	467	703	960	659	450[1]	475[1]	335
	F1	316	426[1]	416[1]	572	825	613	433[1]	435[1]	354
	CoG-F1	209	210	51	131	135	46	17	40	-19
3F-B	CoG	688	825	672	842	1200	825	605[1]	561[1]	336
	F1	311	487[1]	514[1]	653	904	712	550[2]	514[2]	342
	CoG-F1	377	338	158	189	296	113	55	25	-6
4F-A	CoG	554	956	626	993	1094	891	714	575	422
	F1	357	539	587	753	949	802	625	571	369
	CoG-F1	197	417	39	241	145	89	89	4	53

The main effect of Vowel Quality is significant for all speakers as well as for each Foodo speaker [Pooled $F(8,707) = 232$; 1M-K $F(8,171) = 143.2$; 2M-Z $F(8,171) = 106.62$; 3F-B $F(8,171) = 105.15$; 4F-A $F(8,167) = 117.8$]. In each case, $p=0.000$. The model confirms that [-ATR] vowels have statistically significantly higher center of gravities than their [+ATR] counterparts.

Of particular importance to the current study is the role played by center of gravity for cross height vowels [ɪ e] and [ʊ o], whose F1 means are not statistically significant: these data show mixed results within the overall model. Mean center of gravity differences for the front cross-height vowel pairs [ɪ e] are statistically significant for the pooled data and for all individuals but speaker 1M-K. The values of center of gravity for this speaker's [ɪ e] vowels were then submitted to a separate ANOVA: results indicate that the mean differences for this vowel pair are significant, p=.013. The [-ATR] high vowel [ɪ] has a higher center of gravity mean than the [+ATR] mid vowel. On the other hand, mean center of gravity differences for the back cross-height vowel pairs [ʊ o] are significant for only speaker 4F-A. In this case, though, the [+ATR] vowel of the pair, [o], has the significantly higher center of gravity mean. The values of center of gravity for this vowel pair for the pooled data as well as for the other three speakers were then submitted to separate ANOVA. Mean center of gravity differences for [ʊ o] prove to be significant in each separate ANOVA ($p<0.05$). However, the order is reversed for speaker 3F-B. As was the case for 4F-A, the [ATR] vowel of the pair, [o], has the significantly higher center of gravity mean. The results suggest that when height-2 and height-3 vowels such as [ɪ e] and [ʊ o] overlap in for F1 in acoustic space, center of gravity better distinguishes the front cross-height vowels than it does back vowels.

Lastly, the vowels of Foodo have center of gravity means which are overall higher than their F1 means. This effect, however, is most noticeable in front vowels and [ɑ] than in back rounded vowels where center of gravity means are very near or, as in the case of [u], even below their respective F1 means. In a paired t-test of F1 and center of gravity, the mean for the center of gravity for all Foodo vowels is significantly higher (136 Hz) the F1 mean (p=0.000). Paired t-tests for individual speakers (as seen in Table 4.89) show similar results. Center of gravity means are significantly higher than F1 means.

Table 4.89: Paired T-Tests of Center of Gravity and F1 Means for Foodo

Shaded cells indicate mean differences that are not significant, otherwise p<0.05

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]	[+round] [+ATR]	[+round] [-ATR]
Pooled	136	207	46	179	251	31	62
1M-K	136	196	60	190	199	30	91
2M-Z	91	147	21	130	159	-1	43
3F-B	172	272	47	268	274	25	69
4F-A	144	212	58	125	267	71	44

Separate paired t-tests were also conducted on the vowels marked by the feature [±round] alone and combined with the feature [±ATR]. With the exception of speaker 2M-Z [+round][+ATR] vowels, all t-tests were significant (p=0.000), with center of gravity means higher than F1 means. The results show much higher center of gravity mean values for [–round] vowels than for [+round] vowels. When the vowels are split by the feature [round], we see among front vowels and [a], the tendency for center of gravity mean values to be equally higher than F1 mean values. But among round vowels, [+ATR] vowels tend to have a lower center of gravity means in comparison to F1 means than [-ATR] vowels. The one notable exception is speaker 4F-A whose [+round][+ATR] vowels have an overall higher center of gravity to F1 mean than her [+ATR][-ATR] vowels.

These results (to be discussed further in §5) support the findings of Anderson 2007, wherein it was suggested that center of gravity is associated with phonological height in Foodo. In that study, F1 and center of gravity values for front and back vowels were combined according to their phonological height, thereby obscuring the possibility of locating any effects associated with either backness or roundedness. In the pooled ANOVA model, F1 mean values failed to distinguish height 2 [-ATR high] vowels from height 3 [+ATR mid] vowels. These results were also reflected in the individual ANOVA run for each speaker. On the other hand, center of gravity mean values were significant for heights 2 and 3, as well as for the other three heights. These results were best reflected in the results for 1M-K where F1 means were not significant for height 2 and 3 within the one-way ANOVA. Center of gravity means, however, being significantly different, appear to aid the maintenance of phonological height. As is clear from Table 4.89 center of gravity values for the front vowel pair do the lion's share of the work in maintaining an acoustic distinction.

4.5.2 Ikposo

The center of gravity values of the [ATR] harmony pairs of Ikposo were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, /e ɛ/, /o ɔ/, /u ʊ/ and /ə ɑ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group [$F(4,965)=5.43$, p =.000]. The main effect of [ATR] is also significant [$F(1,965)=243.53$, p =.000] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across gender and vowel group.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.90). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all five speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [-+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.90: Univariate ANOVA Results for Center of Gravity in Ikposo

Center of gravity means are significant at p=0.000. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-J	$F(4,187)=70.14$	$F(1,187)=601.75$	√
2M-Jo	$F(4,189)=16.46$	$F(1,189)=44.3$	√
3M-K	$F(4,179)=5.79$	$F(1,179)=17.34$	√
4F-E	$F(4,190)=8.1$	$F(1,190)=123.56$	√
5F-R	$F(4,190)=10.98$	$F(1,190)=235.12$	√

To further investigate center of gravity within the Ikposo vowel system, the center of gravity values of all the vowels of each Ikposo speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.91, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.2 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.91: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Ikposo

Shaded cells indicate mean differences that are not significant – yellow for center of gravity and gray for F1. Diagonal lines indicate cross-height vowels. Superscript numbers indicate which cross-height vowels have means that are not significant. Red lettering indicates a reversed order for cross-height vowels.

Speaker	Vowel	i	ɪ	e	ɛ	ə	ɑ	ɔ	o	ʊ	u
Pooled Data	CoG	362	368[1]	412[1]	503	539	687	511	360[2]	334[2]	246
	F1	246	311	398	523	602	776	551	379[1]	372[1]	275
	CoG-F1	116	-57	14	-20	-63	-89	-40	-19	-38	-29
1M-J	CoG	480	444	390	568	523	747	592	339[1]	373[1]	242
	F1	225	312	344	507	510	783	569	338	389	286
	CoG-F1	255	132	46	61	13	-36	23	1	-16	-44
2M-Jo	CoG	500	394[1]	396[1]	539	615	728	518	344[2]	314[2]	236
	F1	242	310	349	476	601	717	519	346[1]	340[1]	287
	CoG-F1	258	84	47	63	14	11	-1	-2	-26	-51
3F-K	CoG	221	244	282	266	381	399	339	266	231	201
	F1	221	261	317	417	569	736	462	318	275	232
	CoG-F1	0	-17	-35	-151	-188	-337	-123	-52	-44	-31
4F-E	CoG	307	375	460	534	560	782	518	396[1]	342[1]	265
	F1	265	311	466	548	640	826	553	411[1]	398[1]	280
	CoG-F1	42	64	-6	-14	-80	-44	-35	-15	-56	-15
5F-R	CoG	301	383	523	607	617	641	590	455	408	286
	F1	275	363	512	668	687	815	654	482[1]	460[1]	290
	CoG-F1	26	20	11	-61	-70	-174	-64	-27	-52	-4

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Ikposo speaker [Pooled $F(9,975) = 141.27$; 1M-J $F(9,187) = 220.28$; 2M-Jo $F(9,189) = 61.53$; 3M-K $F(9,179) = 44.63$; 4F-E $F(9,190) = 89.86$; 5F-R $F(9,190) = 208.37$]. However, the post-hoc results paint a much different picture than anticipated. Mean center of gravity differences between high vowel pairs are not statistically significant in six of ten cases. In an additional case, that of 2M-Jo, the mean center of gravity difference for front high vowels /i ɪ/ is statistically significant but the order is reversed: [+ATR] /i/ has a higher center of gravity mean than [-ATR] /ɪ/. For speaker 3F-K, only one vowel pair, /o ɔ/ have center of gravity means which are significantly different. Center of gravity mean differences also fail to distinguish cross-height vowels in three of the four cases where F1 means differences are also not significant. In the one case where the center of gravity means are significantly different, 5F-R, the order is reversed with [+ATR] /o/ having the higher center of gravity mean than [-ATR] /ʊ/.

Finally, with the exception of the high front vowels of speakers 1M-J and 2M-Jo, most center of gravity mean values appear to be near or well below the mean values for F1. A paired t-test for F1 and center of gravity shows the mean for the center of gravity for all Ikposo vowels to be 11 Hz lower than the F1 mean (p=0.000). [+round] vowels have center of gravity means significantly lower than F1 means. But [–round] vowels do not necessarily fare better than [+round] vowels in Ikposo. In the case of 3M-K and 5F-R, center of gravity means are significantly lower than F1 means and are not significantly different for the [–round] vowels of 4F-E at all. Finally, for 1M-J and 2M-Jo, [–round][+ATR] vowels have much higher center of gravity to F1 means than [–round][+ATR] vowels.

Table 4.92: Paired T-Tests of Center of Gravity and F1 Means for Ikposo

Shaded cells indicate mean differences that are not significant, otherwise *p*<0.05

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]	[+round] [+ATR]	[+round] [-ATR]
Pooled	-11	3.3	-31	22	-16	-24	39
1M-J	45	81	-8.9	107	56	-21	3.6
2M-Jo	39	79	-20	106	52	-16	-14
3M-K	-86	-104	-62	-75	-139	-41	-83
4F-E	-16	-6.4	-30	-15	2.3	-15	-45
5F-R	-39	-41	-37	-10	-71	-16	-58

4.5.3 Kinande

The center of gravity values of the [ATR] harmony pairs of Kinande were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, [e ɛ], [o ɔ], /u ʊ/ and [ə ɑ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group [$F(4,810)=3.01$, $p=.018$]. The main effect of [ATR] is also significant [$F(1,810)=167$, $p=.000$] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. However, in the two-factor analysis, [ATR] does not interact significantly with Gender [$F(1,810)=.629$]. The main effect of Gender is also not significant [$F(1,810)=1.1$]. These results suggest that while there are significant differences in center of gravity means within the vowel pairs they are not consistent across vowel groups.

Four separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.0125 for four comparisons) with Vowel Group and [ATR] value as factors (Table 4.93). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all four speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.93: Univariate ANOVA Results for Center of Gravity in Kinande

Center of gravity means are significant at p=0.000. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-Kk	$F(4,190)=22.25$	$F(1,190)=180.59$	√
2M-Ks	$F(4,200)=14.82$	$F(1,200)=354.34$	√
3M-J	$F(4,200)=17.48$	$F(1,200)=37.92$	√
4F-Jc	$F(4,200)=10.31$	$F(1,200)=496.88$	√

To further investigate center of gravity within the Kinande vowel system, the center of gravity values of all the vowels of each Kinande speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.0125 for four speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.94, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the

ANOVA results for F1 from §4.2.3 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.94: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Kinande

Shaded cells indicate mean differences that are not significant – yellow for center of gravity and gray for F1. Diagonal lines indicate cross-height vowels. Superscript numbers indicate which cross-height vowels have means that are not significant. Red lettering indicates a reversed order for cross-height vowels.

Speaker	Vowel	i	ɪ	e	ɛ	ə	ɑ	ɔ	o	ʊ	u
Pooled Data	CoG	463	528[1]	460[1]	711	680	800	571	403[2]	412[2]	300
	F1	299	403[1]	381[1]	600	640	713	558	407[1]	397[1]	326
	CoG-F1	164	125	79	111	40	87	13	-4	15	-26
1M-Kk	CoG	392	375[1]	392[1]	507	559	637	502	385[1]	368[1]	289
	F1	304	379	398	555	627	678	515	385[1]	370[1]	327
	CoG-F1	88	-4	-6	-48	-68	-41	-13	0	-2	-38
2M-Ks	CoG	544	774	507	1014	873	1116	646	364	478	317
	F1	270	442	385	622	691	853	624	385	440	277
	CoG-F1	274	332	122	392	182	263	22	-21	38	40
3F-J	CoG	577	461[1]	473[1]	667	590	680	526	376[2]	372[2]	282
	F1	299	403[1]	381[1]	600	640	713	558	407[2]	397[2]	326
	CoG-F1	278	58	92	67	-50	-33	-32	-31	-25	-44
4F-Jc	CoG	338	482[1]	468[1]	656	695	767	610	479	428	311
	F1	277	464[1]	474[1]	672	755	878	642	495	456	307
	CoG-F1	61	18	-6	-16	-60	-111	-32	-16	-28	4

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Kinande speaker [Pooled $F(9,820) = 105.36$; 1M-Kk $F(9,190) = 157.13$; 2M-Ks $F(9,200) = 126.77$; 3M-J $F(9,200) = 38.9$; 4F-Jc $F(9,200) = 284.73$]. At first view, the post-hoc results for center of gravity mean differences appear promising: with the exception of 3 vowel pairs for speaker 3F-J, [-ATR] vowels have higher center of gravity means than their [+ATR] counterparts.

Paired t-tests comparing center of gravity and F1 means are found in Table 4.95. A closer look reveals a fundamental difference between speakers in terms of the distance of center of gravity means from F1 means. The vowels of speakers 1M-Kk and 4F-Jc show consistently lower center of gravity means than F1 means, much like the Ikposo data, while the vowels for speaker 2M-Ks shows consistently higher center of gravity means than F1 means, mirroring the Foodo data. The vowels for 3M-J show mixed results: like Foodo, [–round] vowels have center of gravity mean values higher than F1 and [+round] vowels have center of gravity mean values lower than F1, but unlike Foodo, [+ATR][–round] vowels have much higher center of gravity to F1 mean values that [-ATR][–round] vowels.

Table 4.95: Paired T-Tests of Center of Gravity and F1 Means for Kinande

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]	[+round] [+ATR]	[+round] [-ATR]
Pooled	47	82	-11	90	73	14	-9
1M-Kk	-8.3	4.8	-15	17	-31	-25	-7.2
2M-Ks	169	262	21	204	329	9.4	30
3M-J	40	85	-33	131	31	-37	-29
4F-Jc	-15	-13	-18	7.4	-36	-5.7	-30

4.5.4 LuBwisi

The center of gravity values of the [ATR] harmony pairs of LuBwisi were submitted to a univariate ANOVA with three factors: Vowel Group (/i ɪ/, [e ɛ], [o ɔ], /u ʊ/ and [ə ɑ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group [$F(4,1128)=6.03$, $p=.000$]. The main effect of [ATR] is also significant [$F(1,1128)=2111.77$, p =.000] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across gender and vowel group.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.96). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for the speakers.

Table 4.96: Univariate ANOVA Results for Center of Gravity in LuBwisi

Center of gravity means are significant at p=0.000. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-B	$F(4,220)=88.97$	$F(1,220)=1901.57$	√
2M-H	$F(4,220)=30.92$	$F(1,220)=1170.68$	√
3M-W	$F(4,220)=56.12$	$F(1,220)=1042.92$	√
4F-T	$F(4,218)=18.23$	$F(1,218)=1617.25$	√
5F-Z	$F(4,220)=97.35$	$F(1,220)=1625.85$	√

To further investigate center of gravity within the LuBwisi vowel system, the center of gravity values of all the vowels of each LuBwisi speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.97, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.4 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.97: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for LuBwisi

Shaded cells indicate mean differences that are not significant – yellow for center of gravity and gray for F1. Diagonal lines indicate cross-height vowels. Superscript numbers indicate which cross-height vowels have means that are not significant.

Speaker	Vowel	i	ɪ	e	ɛ	ə	ɑ	ɔ	o	ʊ	u
Pooled Data	CoG	516	667	574	852	811	881	660	471	437	320
	F1	300	434[1]	436[1]	646	728	803	634	466[2]	441[2]	330
	CoG-F1	216	233	138	206	83	78	36	5	-4	-10
1M-B	CoG	703	708	553	868	750	840	571	389[1]	395[1]	299
	F1	280	394[1]	373[1]	582	690	744	568	410[2]	397[2]	315
	CoG-F1	423	314	180	283	60	96	3	-21	-2	-16
2M-H	CoG	315	418	383	575	561	630	549	384	405	315
	F1	304	413[1]	403[1]	589	642	744	577	436	407	333
	CoG-F1	11	5	-20	-14	-81	-114	-28	-52	-2	-18
3M-W	CoG	488	821	589	973	930	1047	702	541	410	323
	F1	301	419[1]	413[1]	637	735	794	620	479	396	331
	CoG-F1	187	402	176	336	195	303	82	62	14	-8
4F-T	CoG	391	625[1]	673[1]	986	973	1121	824	513[1]	513[1]	272
	F1	307	473	533	787	842	998	535	526[1]	535[1]	293
	CoG-F1	84	152	140	199	131	123	289	-13	-22	-21
5F-Z	CoG	682	764[1]	669[1]	868	839	771	654	527[2]	463[2]	392
	F1	308	473[1]	458[1]	642	729	743	641	479[1]	472[1]	377
	CoG-F1	374	291	211	226	110	28	13	48	-9	16

The main effect of Vowel Quality is significant (*p*=0.000) for all speakers as well as for each LuBwisi speaker [Pooled $F(9,1138) = 170.84$; 1M-B $F(9,220) = 99.56$; 2M-H $F(9,220) = 145.5$; 3M-W $F(9,220) = 172.95$; 4F-T $F(9,218) = 93.03$; 5F-Z $F(9,220) = 65.98$]. Again, post-hoc results are mixed. Many of the vowel pairs are distinguished by significantly different center of gravity means. But note that for speakers 1M-B and 5F-Z, that center of gravity mean differences are not significant for high vowel pairs. This is especially important since /i ɪ/ and /u ʊ/ are the only phonological [ATR] harmony pairs. The other [ATR] harmony pairs, [e ɛ], [o ɔ], and [ə ɑ] are not phonologically distinct. Of the remaining three speakers, the center of gravity mean values for speaker 2M-H's vowels are consistently lower than F1 mean values.

Paired t-tests of F1 and center of gravity were conducted for all the vowels and are summarized in Table 4.98. The paired t-test of F1 and center of gravity for speaker 2M-H shows the mean for the center of gravity to be 39 Hz below the F1 mean. Speakers 3M-W and 4F-T, on the other hand, have center of gravity mean values significantly higher than F1 means. The results for these two speakers are similar to those found for the Foodo speakers for [±round] vowels. [-ATR] vowels overall have higher center of gravity to F1 means than [+ATR] vowels of the same [round] feature.

Table 4.98: T-Tests of Center of Gravity and F1 Means for LuBwisi

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]	[+round] [+ATR]	[+round] [-ATR]
Pooled	91	147	4.3	145	148	-.988	11
1M-B	122	208	-11	221	198	-19	-.8
2M-H	-39	-46	-27	-29	-59	-38	-14
3M-W	172	257	40	186	311	34	48
4F-T	82	136	-.344	118	149	-16	19
5F-Z	118	181	20	232	144	34	2.1

4.5.5 Ekiti-Yoruba

The center of gravity values of the [ATR] harmony pairs of the three Ekiti speakers were submitted to a univariate ANOVA with three factors: Vowel Group ([i ɪ], /e ɛ/, /o ɔ/ and [u ʊ]), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group [$F(3,463)=25.53$, p =.000]. The main effect of [ATR] is also significant [$F(1,463)=555.76$, p =.000] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across gender and vowel group.

Three separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.0167 for three comparisons) with Vowel Group and [ATR] value as factors (Table 4.99). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for the speakers.

Table 4.99: Univariate ANOVA Results for Center of Gravity in Ekiti

Center of gravity means are significant at p=0.000. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	[ATR]	[-ATR] Greater
1M-A	$F(3,152)=6.35$	$F(1,152)=120.3$	√
2M-M	$F(3,151)=40.84$	$F(1,151)=194.69$	√
3F-F	$F(4,152)=31.8$	$F(1,152)=302.37$	√

To further investigate center of gravity within the Ekiti vowel system, the center of gravity values of all the vowels of each Ekiti speaker, as well as for the Mọba speaker, were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all Ekiti speakers pooled as well as for each speaker individually (significance level set to 0.0167 for the three Ekiti speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.100, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.5 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean. The results for the Mọba speaker are set apart by a dark horizontal bar.

Table 4.100: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Ekiti and Mọba

Shaded cells indicate mean differences that are not significant – yellow for center of gravity and gray for F1. Diagonal lines indicate cross-height vowels. Superscript numbers indicate which cross-height vowels have means that are not significant. Red lettering indicates a reversed order for cross-height vowels.

Speaker	Vowel	i	ɪ	e	ɛ	ɑ	ɔ	o	ʊ	u
Pooled Data	CoG	260	401^1	357^1	407	573	486	334^1	337^1	241
	F1	242	365^1	360^1	475	741	561	383^1	371^1	271
	CoG-F1	22	-1	-3	-68	-168	-75	-49	-34	-30
1M-A	CoG	285	313^1	310^1	421	421	360	273^1	310^1	203
	F1	253	294	362	454	699	512	342^1	367^1	255
	CoG-F1	32	19	-52	-33	-278	-152	-69	-57	-52
2M-M	CoG	217	310^1	300^1	289	377	429	279^1	288^1	226
	F1	227	361	332	429	577	504	345	321	268
	CoG-F1	-10	-51	-32	-140	-200	-75	-66	-33	-42
3F-F	CoG	277	579	462	512	922	700	451^1	412^1	295
	F1	247	438	387	543	948	666	461	424	291
	CoG-F1	30	141	75	-31	-26	34	-10	-12	4
4F-N	CoG	261	235	285	352	469	440	320	224	239
	F1	248	292	360	491	675	538	385	286	302
	CoG-F1	13	-57	-75	-139	-206	-98	-65	-62	-63

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Ekiti speaker and for the Mọba speaker [Pooled Ekiti $F(8,550) = 40.59$; 1M-A $F(8,171) = 39.51$; 2M-M $F(8,170) = 63.39$; 3F-F $F(8,171) = 194.54$; Mọba 4F-N $F(8,171) = 217.42$]. Considering first the three Ekiti speakers, center of gravity mean differences are largely statistically significant for the [ATR] harmony vowel pairs. Exceptions include the front high vowel pair for speaker 1M-A and the front mid vowel pair for speaker 2M-M. Almost without exception, center of gravity mean values do not differentiate cross-height vowel pairs. As expected, in the case of the Mọba speaker center of gravity means are not significantly different for either of the high vowel pairs. Paired t-tests of F1 and center of gravity were conducted for all the vowels and are summarized in Table 4.101.

Table 4.101 T-Tests of Center of Gravity and F1 Means for Ekiti and Mọba

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]	[+round] [+ATR]	[+round] [-ATR]
Pooled Ekiti	-41	-37	-47	7.2	-67	-39	-54
1M-A	-72	-64	-83	-9.9	-100	-61	-104
2M-M	-71	-84	-55	-21	-125	-54	-55
3F-F	19	36	-3.2	53	26	-2.6	-3.8
4F-N	-82	-91	-72	-31	-131	-64	-80

For both of the Ekiti males and the Mọba speaker, center of gravity mean values are significantly lower than F1 means. Only in the case of speaker 3F-F do vowels have a higher center of gravity mean than F1 mean. However, these results are nowhere as robust as those we saw among Foodo speakers. Indeed, the center of gravity mean values for [–round][-ATR] vowels are not statistically different from F1 means, only the [–round][+ATR] vowels are.

4.5.6 Ifè

The center of gravity values of the [ATR] harmony pairs of Ifè were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] does not interact significantly with Gender and Vowel Group in the 3-factoral analysis [$F(1,399)=.246$] nor with Gender in the 2-factoral analysis [$F(1,399)=.171$]. [ATR] does, however, interact significantly with Vowel Group [*F*(1,399)=17.8, *p*=0.000]. The main effect of [ATR] is also significant [*F*(1,399)=243.53, *p* =.000] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across vowel groups.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.102). Because the front and back vowel pairs differ in rounding, the main effect of Vowel Group is also discussed in these results. [ATR] interacts significantly with Vowel Group for three of the speakers, 2M-Y, 3M-K and 5F-M. The main effect of Vowel Group is only significant for two speakers, 3M-K and 4F-I. The main effect of [ATR], however, is significant for all five speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.102: Univariate ANOVA Results for Center of Gravity in Ifè

Shaded cells indicate mean values which are not significantly different. Where center of gravity means are significantly different, *p*<0.01. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	Vowel Group	[ATR]	[-ATR] Greater
1M-Kv	*F*(1,70)=3.72	*F*(1,70)=.000	*F*(1,70)=146.24	√
2M-Y	*F*(1,93)=24.18	*F*(1,93)=2.58	*F*(1,93)=401.34	√
3M-K	*F*(1,73)=8.11	*F*(1,73)=46.15	*F*(1,73)=292	√
4F-I	*F*(1,73)=.358	*F*(1,73)=41.25	*F*(1,73)=230.7	√
5F-M	*F*(1,78)=13.91	*F*(1,78)=.817	*F*(1,78)=57.91	√

To further investigate center of gravity within the Ifè vowel system, the center of gravity values of all the vowels of each Ifè speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.103, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.6 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.103: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Ifè

Shaded cells indicate mean differences that are not significant.

Speaker	Vowel	i	e	ɛ	ɑ	ɔ	o	u
Pooled Data	CoG	415	483	637	826	635	416	306
	F1	300	426	590	780	632	429	316
	CoG-F1	115	57	47	49	3	-13	-10
1M-Kv	CoG	417	411	508	700	526	393	276
	F1	256	386	528	746	560	393	285
	CoG-F1	161	25	-20	-46	-34	0	-9
2M-Y	CoG	327	383	531	743	595	350	289
	F1	292	377	541	746	586	368	316
	CoG-F1	35	6	-10	-3	9	-18	-27
3M-K	CoG	415	492	659	777	612	379	334
	F1	289	363	519	688	590	391	346
	CoG-F1	126	129	140	89	22	-12	-12
4F-I	CoG	512	589	845	981	731	494	316
	F1	366	517	703	895	736	517	336
	CoG-F1	146	72	142	86	-5	-23	-20
5F-M	CoG	401	569	643	910	697	480	312
	F1	289	503	667	818	686	488	298
	CoG-F1	112	66	-24	92	11	-8	14

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Ifè speaker [Pooled $F(6,700) = 291.89$; 1M-Kv $F(6,126) = 82.56$; 2M-Y $F(6,150) = 242.39$; 3M-K $F(6,130) = 202.54$; 4F-I $F(6,128) = 116.61$; 5F-M $F(6,138) = 148.57$]. With the exception of the front vowel pair for speaker 5F-M, Post-Hoc results indicate that [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts. Paired t-tests (Table 4.104) comparing center of gravity and F1 means help to interpret these results.

Table 4.104: T-Tests of Center of Gravity and F1 Means for Ifè

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]
Pooled	34	66	-6.5	87	46
1M-Kv	12	30	-13	99	-33
2M-Y	-1.26	6.8	-10	19	-6.4
3M-K	69	121	-.05	128	114
4F-I	58	112	-16	111	114
5F-M	37	65	5.5	90	42

Since [+round] vowels have either significantly lower center of gravity means or are not significantly different than F1 means, only [–round] vowels are considered for comparison for [ATR]. Upon examination, we see for speaker 1M-Kv that the center of gravity means of [-ATR] vowels are significantly lower than F1 means. In the case of 2M-Y, the means are not statistically different. For speaker 5F-M, the [+ATR] vowels have a higher center of gravity to F1 mean than [-ATR] vowels. Speakers 3M-K and 4F-I, on the other hand, have results similar to those found among Foodo speakers.

4.5.7 Dibole

The center of gravity values of the [ATR] harmony pairs of Dibole were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group in the 3-factoral analysis [$F(1,392)=5.12$, $p=.024$] but not with Gender nor with Vowel Group in the 2-factoral analysis [$F(1,392)=.06$; $F(1,392)=.786$]. The main effect of [ATR], however, is significant

[$F(1,392)=573.75$, p =.000] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across vowel groups.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.105). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all five speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.105: Univariate ANOVA Results for Center of Gravity in Dibole

Shaded cells indicate mean values which are not significantly different. Where center of gravity means are significantly different, $p<0.01$. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	Vowel Group	[ATR]	[-ATR] Greater
1F-MN	$F(1,76)=38.42$	$F(1,76)=207.13$	$F(1,76)=518.75$	√
2F-F	$F(1,76)=1.34$	$F(1,76)=23.16$	$F(1,76)=340.53$	√
3F-S	$F(1,76)=2.39$	$F(1,76)=18.8$	$F(1,76)=135.61$	√
4M-C	$F(1,76)=8.14$	$F(1,76)=1.04$	$F(1,76)=859.63$	√
5M-L	$F(1,76)=21.63$	$F(1,76)=6.59$	$F(1,76)=568.35$	√

To further investigate center of gravity within the Dibole vowel system, the center of gravity values of all the vowels of each Dibole speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.106, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.7 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.106: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Dibole

Speaker	Vowel	i	e	ɛ	ɑ	ɔ	o	u
Pooled Data	CoG	357	440	647	820	594	380	278
	F1	295	382	569	773	592	400	334
	CoG-F1	62	58	78	47	2	-20	-56
1F-MN	CoG	505	494	770	837	593	397	299
	F1	342	434	669	785	599	405	346
	CoG-F1	163	60	101	52	-6	-8	-47
2F-F	CoG	339	416	575	747	541	361	288
	F1	291	386	532	744	566	384	338
	CoG-F1	48	30	43	3	-25	-23	-50
3F-S	CoG	360	550	773	1019	675	450	304
	F1	313	426	622	839	653	468	359
	CoG-F1	47	124	151	180	22	-18	-55
4M-C	CoG	283	411	651	736	667	376	278
	F1	272	354	532	689	616	384	329
	CoG-F1	11	57	119	47	51	-8	-51
5M-L	CoG	300	328	450	828	495	315	209
	F1	257	313	491	812	538	357	298
	CoG-F1	43	15	-41	16	-43	-42	-89

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Dibole speaker [Pooled $F(6,713) = 375.41$; 1F-MN $F(6,133) = 162.31$; 2F-F

F(6,153) = 195.88; 3F-S *F*(6,133) = 158.68; 4M-C *F*(6,133) = 528.73; 5M-L *F*(6,133) = 589.93]. As indicated in Table 4.106, [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts. The center of gravity and F1 means compared via paired t-tests are found in Table 4.85.

Table 4.107: T-Tests of Center of Gravity and F1 Means for Dibole

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]
Pooled	22	61	-27	60	62
1F-MN	45	94	-20	111	76
2F-F	-1.4	31	-34	39	24
3F-S	57	113	-17	86	141
4M-C	32	58	-2.5	34	83
5M-L	-19	8.3	-56	29	-12

The [+round] vowels tend to have center of gravity means significantly below the means for F1. For two of the speakers, [–round][-ATR] vowels either have center of gravity means slightly above F1 means (2F-F), or slightly below F1 means (5M-L). The net effect on all the vowels for these two speakers is a center of gravity mean that is not statistically significant from F1 means or a mean significantly below F1 means. The results for the vowels of speakers 1F-MN and 4M-C are moderately robust; but only the vowels of speaker 3F-S display results approaching those for the Foodo speakers: [–round][-ATR] vowels have center of gravity means 141 Hz above F1 means.

4.5.8 Mbosi

The center of gravity values of the [ATR] harmony pairs of Mbosi were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group [$F(1,372)=36.56$, $p=0.000$]. The main effect of [ATR] is also significant [$F(1,372)=355.45$, $p=.000$] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across gender and vowel groups.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.108). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all five speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.108: Univariate ANOVA Results for Center of Gravity in Mbosi

Shaded cells indicate mean values which are not significantly different. Where center of gravity means are significantly different, $p<0.01$. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	Vowel Group	[ATR]	[-ATR] Greater
1M-C	$F(1,66)=10.93$	$F(1,66)=53.66$	$F(1,66)=211.59$	√
2M-Le	$F(1,76)=1.88$	$F(1,76)=.019$	$F(1,76)=128.26$	√
3M-O	$F(1,66)=10.73$	$F(1,66)=.343$	$F(1,66)=10.79$	√
4F-Ly	$F(1,76)=66.9$	$F(1,76)=126.22$	$F(1,76)=290.44$	√
5F-M	$F(1,76)=1.74$	$F(1,76)=3.86$	$F(1,78)=101.98$	√

To further investigate center of gravity within the Mbosi vowel system, the center of gravity values of all the vowels of each Mbosi speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.109, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.8 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.109: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Mbosi

Shaded cells indicate mean differences that are not significant.

Speaker	Vowel	i	e	ɛ	ɑ	ɔ	o	u
Pooled Data	CoG	334	437	613	761	541	438	281
	F1	297	416	521	764	558	431	318
	CoG-F1	37	21	92	-3	-17	7	-37
1M-C	CoG	283	355	417	578	475	377	292
	F1	332	389	527	713	518	429	341
	CoG-F1	-49	-34	-110	-135	-43	-52	-49
2M-Le	CoG	263	380	472	714	486	368	250
	F1	290	379	470	694	519	376	316
	CoG-F1	-33	1	2	20	-33	-8	-99
3M-O	CoG	288	336	336	493	350	317	262
	F1	306	357	432	707	480	354	310
	CoG-F1	-18	-21	-96	-214	-130	-37	-48
4F-Ly	CoG	520	568	1062	1050	681	508	305
	F1	281	470	574	917	624	477	332
	CoG-F1	239	98	488	133	57	31	-27
5F-M	CoG	311	544	777	971	710	531	296
	F1	277	484	603	791	650	481	292
	CoG-F1	34	60	174	180	60	50	4

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Mbosi speaker [Pooled $F(6,671) = 98.36$; 1M-C $F(6,123) = 364.26$; 2M-Le $F(6,132) = 418.68$; 3M-O $F(6,123) = 158.77$; 4F-Ly $F(6,133) = 197.11$; 5F-M $F(6,132) = 174.25$]. With the exception of the front [ATR] harmony pair for speaker 3M-O, the center of gravity means for [-ATR] vowels are all significantly higher than the means for their [+ATR] counterparts. The center of gravity and F1 means compared via paired t-tests are found in Table 4.110.

Table 4.110: T-Tests of Center of Gravity and F1 Means for Mbosi

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]
Pooled	14	36	-17	28	44
1M-C	-68	-82	-47	-41	-123
2M-Le	-16	-.873	-37	-13	11
3M-O	-84	-87	-78	-19	-155
4F-Ly	146	239	21	169	310
5F-M	81	112	39	47	177

The results for the comparison of center of gravity and F1 means are clearly separated by gender. All three males have vowels with significantly lower center of gravity means than F1 means. The vowels of the two females, on the other hand, display values similar to those of the Foodo speakers. The center of gravity mean values for speaker 4F-Ly are especially robust, with [–round][-ATR] vowels having center of gravity means over 300 Hz higher than their F1 means.

4.5.9 Mbonge

The center of gravity values of the [ATR] harmony pairs of Mbonge were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group in the 3-factoral analysis [$F(1,406)=12.06$, $p=0.001$] but does not interact significantly with Gender [$F(1,406)=.246$] in the 2-factoral analysis [$F(1,406)=.907$]. [ATR] does, however, interact significantly with Vowel Group [$F(1,406)=11.66$, $p=0.001$]. The main effect of [ATR] is also significant

[F(1,406)=58.3, p =.000] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across vowel groups.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.111). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all five speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.111: Univariate ANOVA Results for Center of Gravity in Mbonge

Shaded cells indicate mean values which are not significantly different. Where center of gravity means are significantly different, $p<0.01$. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	Vowel Group	[ATR]	[-ATR] Greater
1M-Jo	F(1,82)=5.97	F(1,82)=4.99	F(1,82)=82.23	√
2M-J	F(1,79)=.447	F(1,79)=.495	F(1,79)=71.7	√
3M-P	F(1,80)=5.3	F(1,80)=13.73	F(1,80)=35.99	√
4F-J	F(1,78)=8.08	F(1,78)=.074	F(1,78)=14.67	√
5F-B	F(1,75)=8.13	F(1,75)=12.08	F(1,75)=7.9	√

To further investigate center of gravity within the Mbonge vowel system, the center of gravity values of all the vowels of each Mbonge speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.112, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.9 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.112: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Mbonge

Shaded cells indicate mean differences that are not significant – yellow for center of gravity and gray for F1. Superscript numbers indicate which cross-height vowels have means that are not significant.

Speaker	Vowel	i	e	ɛ	ɑ	ɔ	o	u
Pooled Data	CoG	319	382	418	578	425	345	256
	F1	300	360	475	691	517	382	304
	CoG-F1	19	22	-57	-113	-92	-37	-48
1M-Jo	CoG	289	295	253	519	394	293	255
	F1	292	316	470	664	521	348	300
	CoG-F1	-3	-21	-217	-145	-127	-55	-45
2M-J	CoG	225	290	369	413	357	290	238
	F1	250	313	461	519	437	346	283
	CoG-F1	-25	-23	-92	-106	-80	-56	-45
3M-P	CoG	282	307	367	403	323	297	230
	F1	301[1]	322[1]	414	669	462	365	296
	CoG-F1	-19	-15	-47	-266	-139	-68	-66
4F-J	CoG	271	421	432	660	460	388	257
	F1	330	421	500	765	544	403	305
	CoG-F1	-59	0	-68	-105	-84	-15	-48
5F-B	CoG	531	608	607	898	592	458	301
	F1	331	432	549	837	622	448	340
	CoG-F1	200	176	58	61	-30	10	-39

The main effect of Vowel Quality is significant (*p*=0.000) for all speakers as well as for each Mbonge speaker [Pooled $F(6,709) = 62.81$; 1M-Jo $F(6,142) = 95.99$; 2M-J $F(6,136) = 78.6$; 3M-P $F(6,137) = 46.96$; 4F-J $F(6,135) = 157.25$; 5F-B $F(6,131) = 34.01$]. Center of gravity differences do not fare as well in the Mbonge data as they have in other datasets seen so far. Center of gravity mean differences in [ATR] harmony pairs for three of the speakers fail to be statistically significant. There is also a wide-spread tendency for center of gravity mean values to be lower than their F1 mean values. The paired t-tests of these comparisons are summarized in Table 4.113.

Table 4.113: T-Tests of Center of Gravity and F1 Means for Mbonge

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]
Pooled	-43	-32	-59	20	-83
1M-Jo	-72	-69	-76	-14	-128
2M-J	-62	-63	-60	-24	-99
3M-P	-88	-85	-91	-17	-148
4F-J	-54	-58	-49	-29	-85
5F-B	63	125	-19	188	60

Only the vowels of speaker 5F-B, whose [ATR] harmony pairs are not distinguished by center of gravity differences, have center of gravity mean values higher than F1 means.

4.5.10 Londo

The center of gravity values of the [ATR] harmony pairs of Londo were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] interacts significantly with Gender and Vowel Group in the 3-factoral analysis [$F(1,381)=10.06$, $p=0.002$]. The main effect of [ATR] is also significant [$F(1,381)=139.43$, $p=.000$] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across gender or vowel groups.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.114). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all five speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.114: Univariate ANOVA Results for Center of Gravity in Londo

Shaded cells indicate mean values which are not significantly different. Where center of gravity means are significantly different, $p<0.01$. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	Vowel Group	[ATR]	[-ATR] Greater
1M-CE	$F(1,71)=34.95$	$F(1,71)=20.39$	$F(1,71)=156.96$	√
2M-W	$F(1,72)=1.1$	$F(1,72)=2.77$	$F(1,72)=269.78$	√
3M-I	$F(1,74)=52.22$	$F(1,74)=21.37$	$F(1,74)=373.03$	√
4F-M	$F(1,76)=.828$	$F(1,76)=18.78$	$F(1,76)=82.88$	√
5F-H	$F(1,76)=32.86$	$F(1,76)=54.47$	$F(1,76)=208.22$	√

To further investigate center of gravity within the Londo vowel system, the center of gravity values of all the vowels of each Londo speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.115, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.10 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.115: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Londo

Speaker	Vowel	i	e	ɛ	ɑ	ɔ	o	u
Pooled Data	CoG	337	401	576	783	546	400	299
	F1	284	382	518	750	576	417	324
	CoG-F1	53	19	58	33	-30	-17	-25
1M-CE	CoG	280	299	354	546	442	287	231
	F1	273	346	458	614	542	352	300
	CoG-F1	7	-47	-104	-68	-100	-65	-69
2M-W	CoG	274	334	505	751	511	360	266
	F1	274	345	528	725	555	369	334
	CoG-F1	0	-11	-23	26	-44	-9	-68
3M-I	CoG	325	356	427	656	497	341	317
	F1	312	341	444	666	494	360	336
	CoG-F1	13	15	-17	-10	3	-19	-19
4F-M	CoG	334	391	455	740	496	418	291
	F1	266	420	557	780	568	445	305
	CoG-F1	68	-29	-102	-40	-72	-27	-14
5F-H	CoG	484	619	1095	1224	786	580	382
	F1	297	457	592	965	722	546	355
	CoG-F1	187	162	503	259	62	34	27

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Londo speaker [Pooled $F(6,677) = 99.94$; 1M-CE $F(6,133) = 135.81$; 2M-W $F(6,125) = 256.69$; 3M-I $F(6,131) = 278.89$; 4F-M $F(6,127) = 167.74$; 5F-H $F(6,133) = 236.03$]. [-ATR] vowels have significantly higher center of gravity mean values than their [+ATR] counterparts. These results are evaluated in the paired t-tests summarized in Table 4.116.

Table 4.116: T-Tests of Center of Gravity and F1 Means for Londo

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]
Pooled	13	41	-24	36	46
1M-CE	-59	-45	-33	-14	-82
2M-W	-16	-2	-38	-5.5	1.4
3M-I	-4.4	.4	-11	14	-13
4F-M	-35	-33	-38	-11	-71
5F-H	177	278	42	175	381

Center of gravity mean values are either not significantly different from F1 mean values or fall below F1 means for four of the five speakers. In the case of the fifth speaker, 5F-H, center of gravity mean values pattern like those for the Foodo speakers, with very robust results for [–round][-ATR] vowels. These vowels have center of gravity mean values 381 Hz higher than their F1 mean values, or more than twice that of the [–round][+ATR] vowels.

4.5.11 Tuwuli

The center of gravity values of the [ATR] harmony pairs of Tuwuli were submitted to a univariate ANOVA with three factors: Vowel Group (/e ɛ/ and /o ɔ/), [ATR] value ([+ATR] or [-ATR]) and Gender (male or female). [ATR] does not interact significantly with Gender and Vowel Group in the 3-factoral analysis [$F(1,390)=1.38$] but does interact significantly with Gender and with Vowel Group in the 2-factoral analyses [$F(1,390)=9.03$, $p=0.003$; $F(1,390)=14.07$, $p=0.000$]. The main effect of [ATR] is also significant [$F(1,390)=68.48$, p =.000] with [-ATR] vowels having significantly higher center of gravities than [+ATR] vowels. These results suggest that there are significant differences in center of gravity means within the vowel pairs but that they are not consistent across gender or across vowel groups.

Five separate univariate ANOVA, one for each speaker, were then run (significance level set to 0.01 for five comparisons) with Vowel Group and [ATR] value as factors (Table 4.117). [ATR] interacts significantly with Vowel Group for all speakers. The main effect of [ATR] is also significant for all five speakers. These results confirm that while [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts the effect is not consistent across vowel groups for some speakers.

Table 4.117: Univariate ANOVA Results for Center of Gravity in Tuwuli

Shaded cells indicate mean values which are not significantly different. Where center of gravity means are significantly different, $p<0.01$. A check indicates that the center of gravity mean for the [-ATR] vowel is greater than the mean for its [+ATR] counterpart.

	[ATR]* Vowel Group	Vowel Group	[ATR]	[-ATR] Greater
1M-J	$F(1,76)=2.96$	$F(1,76)=28.83$	$F(1,76)=149.87$	√
2M-An	$F(1,74)=2.43$	$F(1,74)=11.31$	$F(1,74)=119.82$	√
3M-A	$F(1,76)=76.41$	$F(1,76)=.48$	$F(1,76)=249.44$	√
4F-F	$F(1,76)=27.9$	$F(1,76)=120.27$	$F(1,76)=9.36$	√
5F-T	$F(1,76)=.035$	$F(1,76)=8.04$	$F(1,76)=42.18$	√

To further investigate center of gravity within the Tuwuli vowel system, the center of gravity values of all the vowels of each Tuwuli speaker were submitted to a one-way ANOVA with center of gravity as the dependent variable and vowel quality as the independent factor. This model was run for all speakers pooled as well as for each speaker individually (significance level set to 0.01 for five speakers). The mean center of gravity values for the group and each speaker are summarized in the first row for each speaker in Table 4.118, along with pairwise comparisons as determined by a Tukey Post-Hoc test. The second row for each speaker in the table reiterates the ANOVA results for F1 from §4.2.11 for comparative purposes. The third row is the difference of the center of gravity mean and corresponding F1 mean.

Table 4.118: One-Way ANOVA Results for Center of Gravity and F1 with Center of Gravity and F1 Differential for Tuwuli

Shaded cells indicate mean differences that are not significant.

Speaker	Vowel	i	e	ɛ	ɑ	ɔ	o	u
Pooled Data	CoG	480	549	633	800	597	401	306
	F1	302	375	526	821	611	409	329
	CoG-F1	178	174	107	-21	-14	-8	-23
1M-J	CoG	543	521	749	894	670	367	267
	F1	271	334	510	790	615	379	300
	CoG-F1	272	187	239	104	55	-12	-33
2M-An	CoG	363	441	574	722	549	371	291
	F1	276	345	519	791	581	386	327
	CoG-F1	87	96	55	-69	-32	-15	-36
3M-A	CoG	341	397	448	830	516	340	292
	F1	316	345	451	772	527	355	319
	CoG-F1	25	52	-3	58	-11	-15	-27
4F-F	CoG	829	970	903	828	733	484	363
	F1	319	423	590	848	711	454	343
	CoG-F1	510	547	313	-20	22	30	20
5F-T	CoG	325	411	488	704	519	446	316
	F1	326	428	559	926	623	473	356
	CoG-F1	-1	-17	-71	-222	-104	-27	-40

The main effect of Vowel Quality is significant (p=0.000) for all speakers as well as for each Tuwuli speaker [Pooled $F(6,687) = 92.11$; 1M-J $F(6,133) = 109.38$; 2M-An $F(6,131) = 108.89$; 3M-A $F(6,133) = 516.22$; 4F-F $F(6,133) = 32.86$; 5F-T $F(6,129) = 101.45$]. With the exception of the front [ATR] harmony pair for speaker 4F-F, [-ATR] vowels all have significantly higher center of gravity means than their [+ATR] counterparts. The results of paired t-tests comparing center of gravity and F1 means are found in Table 4.119.

Table 4.119: T-Tests of Center of Gravity and F1 Means for Tuwuli

Shaded cells indicate mean differences that are not significant, otherwise $p<0.05$

Speaker	All Vowels	[–round]	[+round]	[–round] [+ATR]	[–round] [-ATR]
Pooled	56	111	-15	176	44
1M-J	116	201	3.5	230	172
2M-An	11	41	-28	91	8.7
3M-A	11	33	-18	39	27
4F-F	203	337	24	528	147
5F-T	-64	-70	-57	-227	-138

The results are mixed for Tuwuli. The center of gravity mean values for all of Speaker 5F-T's vowels are significantly lower than F1 means. For Speaker 1M-J, the mean center of gravity values compared to F1 values are similar to the results for the Foodo speakers. The results for the center of gravity values for the vowels of speakers 2M-An and 3M-A are only moderately higher than F1 values. However, [–round][+ATR] vowels have more robust results than the [–round][-ATR] vowels. The center of gravity values for Speaker 4F-F depart from the rest of the speakers in an important way. She has considerable displacement of center of gravity from F1 in front vowels. Both [+ATR] front vowels, for example, have mean center of gravities more than 500 Hz higher than their respective F1 means. This speaker has a center of gravity mean for /e/ in the same range as the means for /ɪ/ for some speakers of Foodo. However, her center of gravity mean for /i/ is 141 Hz higher than the highest mean for /i/ in Foodo (3F-B). In addition, with the exception of /a/, all of Speaker 4F-F's back vowels have significantly higher center of gravity means than F1 means. Speaker 4F-F's unusually high center of gravity means appear to be systematic, i.e. a possibly idiosyncratic feature of this speaker's articulatory setting.

CHAPTER 5

DISCUSSION

5.1 Introduction

While Chapter 4 presents the acoustic facts for each of the languages featured in this study, this chapter seeks to derive linguistic meaning from these results sections and to fit that meaning into the larger picture of what has already been discovered about African vowel systems with [ATR] harmony.

The major challenge to generalizing the findings of the results section arises from the level of inter-speaker variation found within each language. By and large, in the pooled univariate ANOVA models, it was shown that [ATR] interacts significantly with Vowel Group and Gender necessitating a speaker by speaker analysis of the dependent factor. And while the univariate ANOVA models do give us a general idea of how the [ATR] value of any given dependent factor is interacting with other factors, the best picture of how each speaker's vowels fit within an overall model is to be found within the one-way ANOVA models.

In this chapter, the results of the one-way ANOVA models for each speaker are summarized by language followed by a brief commentary of the acoustic behavior of the vowel system of each language. These individual charts and commentaries are then distilled in a larger summary chart that seeks to integrate the trends in each language. This summary chart, along with the observations drawn from individual speakers, will serve as the springboard from which to dive into a deeper understanding of both the acoustic nature and phonological behavior of the 7-vowel languages with [ATR] harmony in this study. In so doing, this section seeks specifically to address the following question: given any 7-vowel system with [ATR] harmony, can we know empirically whether the degree 2 vowels follow the acoustic behavior of the [-ATR][+high] vowels, or do they follow the acoustic behavior of the [+ATR][-high] of the 9-vowel systems with CHVH systems? In other words, are the height 2 vowels [ɪ ʊ] or [e o]?

5.2 Language Summaries

5.2.1 Foodo

Table 5.1: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Foodo

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-K	F1	F2	B1	ΔB1	S.F.	CoG	2M-Z	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√+		X	X	√-	i ɪ	√-	√+		√+	X	√-
ɪ e	X	√+	X	X	√+	X	ɪ e	X	√-	√-	√-	√+	√-
e ɛ	√-	√+		X	√+	√-	e ɛ	√-	√+		X	X	√-
o ɔ	√-	X		√-	X	√-	o ɔ	√-	X		√-	√+	√-
o ʊ	X	√+	√-	√-	√+	X	o ʊ	X	√+	X	X	√+	X
ʊ u	√-	X		X	X	√-	ʊ u	√-	√-		√+	X	√-
3F-B	F1	F2	B1	ΔB1	S.F.	CoG	4F-A	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√+		X	X	√-	i ɪ	√-	X		√-	X	√-
ɪ e	X	√-	√-	√-	√+	√-	ɪ e	√+	√-	√-	√-	√+	√-
e ɛ	√-	√+		√-	√+	√-	e ɛ	√-	X		√-	√+	√-
o ɔ	√-	X		X	√+	√-	o ɔ	√-	X		√-	X	√-
o ʊ	X	√+	√-	√-	√+	X	o ʊ	√+	√+	√-	√-	√-	√+
ʊ u	√-	√-		X	X	√-	ʊ u	√-	X		√+	√-	√-

Foodo is a 9-vowel language with Cross-Height Vowel Harmony (CHVH) and the following vowel inventory: /i ɪ e ɛ ɑ ɔ o ʊ u/. The main acoustic correlate of [ATR] in Foodo is F1, with [-ATR] vowels having statistically significantly higher F1 means than their [+ATR] counterparts. F1 mean frequencies do not, however, reliably distinguish between cross-height vowel pairs, e.g., [ɪ] vs. [e]. F2 means do not reliably distinguish between [ATR] harmony pairs, failing to do so for /o ɔ/ in all speakers and for all vowel pairs in one speaker. For those vowels which do have statistically significantly different F2 means, [+ATR] vowels tend to have the higher means in front vowels but [-ATR] vowels tend to be higher in back vowels. In other words, [-ATR] vowels tend to have more centralized F2 mean values. F2 means are significantly different in all cross-height vowel pairs but as there is no consistency in which vowel of the [ATR] pairs will have the higher means – [+ATR] or [-ATR] – F2 cannot be considered a reliable measure of [ATR] in Foodo.

Of the secondary acoustic correlates associated with [ATR] differences within vowel pairs, center of gravity is the most promising. Not only are the center of gravity means of [-ATR] vowels significantly higher than their [+ATR] counterparts, but center of gravity in general is robustly higher than F1. Center of gravity also out performs ΔB1 for [ATR] pairs. In instances where [+ATR] high vowel means have a significantly greater displacement from predicted values than their [-ATR] counterparts (and thus wider bandwidths), [-ATR] center of gravity means are still significantly greater than [+ATR] means. The implications are that a constriction, most likely in the pharyngeal region, as well as overall tension in the cavity walls of the vocal tract forces center of gravity values much higher than F1. However, bandwidth and the highly derivative measure of Normalized A1-A2 (the measure of spectral flatness) do help to differentiate cross-height vowels which overlap for F1. The [+ATR] mid vowels tend to have significantly narrower bandwidths and steeper spectral slopes than the [-ATR] high vowels with which they overlap in F1.

The overall picture of Foodo acoustics is one in which F1 plays the major role in differentiating [ATR] value within vowel pairs but not vowel quality. Bandwidth and Center of Gravity differences which are presumably perceptually salient aid to disambiguate overlapping vowel qualities.

5.2.2 Ikposo

Table 5.2: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Ikposo

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-J	F1	F2	B1	ΔB1	S.F.	CoG	2M-Jo	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√+		X	√-	X	i ɪ	√-	X		√+	√-	√+
ɪ e	√+	√-	X	X	X	√-	ɪ e	√+	X	X	X	√+	X
e ɛ	√-	√+		√-	√+	√-	e ɛ	√-	√+		√-	√+	√-
ə ɑ	√-	X		√-	√-	√-	ə ɑ	√-	√+		√-	√+	√-
o ɔ	√-	√-		√-	X	√-	o ɔ	√-	√-		√-	√+	√-
o ʊ	√-	√+	√-	√-	√+	X	o ʊ	X	√+	√-	√-	X	X
ʊ u	√-	√+		X	X	√-	ʊ u	√-	√-		X	X	X
3M-K	F1	F2	B1	ΔB1	S.F.	CoG	4F-E	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	X		√-	X	X	i ɪ	√-	X		√-	X	X
ɪ e	√+	√-	X	X	√+	√+	ɪ e	√+	X	√-	√-	√+	√+
e ɛ	√-	√+		√-	X	X	e ɛ	√-	X		√-	√+	√-
ə ɑ	√-	X		X	X	X	ə ɑ	√-	X		√-	X	√-
o ɔ	√-	√-		√-	X	√-	o ɔ	√-	√-		√-	√+	√-
o ʊ	√+	X	X	X	X	√+	o ʊ	X	X	X	√-	X	X
ʊ u	√-	X		X	X	X	ʊ u	√-	X		X	X	√-
5F-R	F1	F2	B1	ΔB1	S.F.	CoG							
i ɪ	√-	X		√-	X	√-							
ɪ e	√+	√-	√-	√-	√+	√+							
e ɛ	√-	X		√-	X	√-							
ə ɑ	√-	√+		X	X	X							
o ɔ	√-	X		√-	X	√-							
o ʊ	X	√+	√-	√-	X	√+							
ʊ u	√-	√+		√-	X	√-							

Ikposo is a 10-vowel language with Cross-Height Vowel Harmony (CHVH) and the following vowel inventory: /i ɪ e ɛ ə ɑ ɔ o ʊ u/. The main acoustic correlate of [ATR] in Ikposo is F1, with [-ATR] vowels having statistically significantly higher F1 means than their [+ATR] counterparts. F1 mean frequencies also distinguish between cross-height vowel pairs, though not consistently among the back pair. F2 means do not reliably distinguish between [ATR] harmony pairs, failing to do so in half of the 25 [ATR] harmony pairs observed in the data. F2 means are significantly different in six of the ten cross-height vowel pairs, with [-ATR] high vowels having higher means in the front pair but lower means in the back pair.

Of the secondary acoustic correlates associated with [ATR] differences within vowel pairs, only bandwidth seems to help disambiguate overlapping vowel qualities, but not consistently. ΔB1 results for cross-height vowels parallel those of the observed B1 results in all but one case, the back vowel pair for speaker 4F-E. This vowel pair will be considered more closely below. In general, ΔB1 results are more robust than those of Normalized A1-A2. ΔB1 means are statistically significantly different in thirteen more [ATR] pairs than for Normalized A1-A2.

Center of gravity mean differences are often not significantly different among high vowel pairs, or the [+ATR] vowel of the pair may have the significantly higher center of gravity mean, contra expectation. For those vowel pairs where the center of gravity mean of the [-ATR] vowel is significantly different from its [+ATR] counterpart, the [-ATR] vowel also has a mean lower than its F1 mean. This raises questions of the perceptual salience of any center of gravity differences between vowel pairs, statistically significant or not.

Lastly, there is the case of speaker 4F-E, whose back cross-height vowels /ʊ o/ are not differentiated by any of the acoustic measures except ΔB1. While it is possible that these vowels have either merged or partially merged for this speaker, this conclusion is somewhat tenuous. More likely, given the statistically significant difference in ΔB1 mean, is that the statistical model used for observed bandwidth is too sensitive. The ANOVA run for this speaker's vowels (Table 4.34) considered the mean bandwidth differences for these vowels non-significant within the overall model. As noted in §4.3.2., when this speaker's cross-height vowels were submitted to a separate ANOVA, B1 mean differences were statistically significantly different. Mean bandwidth differences of 53 Hz (for the [-ATR] vowel) and 28 Hz (for the [+ATR] vowel) may be sufficiently salient for speakers and listeners to discern the quality of vowels overlapping in acoustic space. Even as a non-native speaker of Ikposo (the language I am most acquainted with among these datasets), I can clearly hear the different quality of her vowels, especially the back vowels. The [+ATR] mid vowel /o/, sounds "full" or "resonant" while the [-ATR] sounds slightly constricted, "choked" or "tight."

5.2.3 Kinande

Table 5.3: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Kinande

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-Kk	F1	F2	B1	ΔB1	S.F.	CoG	2M-Ks	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√+		√+	√-	√+	i ɪ	√-	√+		X	X	√-
ɪ e	√+	√+	X	X	X	X	ɪ e	√-	X	X	√-	X	√-
e ɛ	√-	√+		√-	X	√-	e ɛ	√-	√+		√-	√+	√-
ə ɑ	√-	X	X	X	X	√-	ə ɑ	√-	X	√-	√-	X	√-
o ɔ	√-	X		√-	X	√-	o ɔ	√-	X		√-	√+	√-
o ʊ	X	√+	X	X	√-	X	o ʊ	√-	√+	X	X	√+	√-
ʊ u	√-	X		X	X	√-	ʊ u	√-	√-		√+	√-	√-
3M-J	F1	F2	B1	ΔB1	S.F.	CoG	4F-Jc	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√+		X	√-	√+	i ɪ	√-	√+		X	X	√-
ɪ e	X	√+	X	X	X	X	ɪ e	X	X	X	X	√+	X
e ɛ	√-	√+		√-	X	√-	e ɛ	√-	√+		√-	√+	√-
ə ɑ	√-	X	√-	√-	√-	X	ə ɑ	√-	X	√-	√-	X	√-
o ɔ	√-	X		√-	X	√-	o ɔ	√-	X		√-	√+	√-
o ʊ	X	√+	X	X	X	X	o ʊ	√+	√+	√-	√-	√+	√+
ʊ u	√-	X		√-	X	X	ʊ u	√-	X		√-	√+	√-

Kinande is a 7-vowel language with the following vowel inventory: /i ɪ ɛ ɑ ɔ ʊ u/. [ATR] harmony is triggered by [+ATR] high vowels which also produces [+ATR] variants of [-ATR] mid and low vowels, [e o ə]. The main acoustic correlate of [ATR] in Kinande is F1, with [-ATR] vowels having statistically significantly higher F1 means than their [+ATR] counterparts. This is true whether both members of the [ATR] harmony pair are underlyingly distinct or if one of the members is produced by means of [ATR] harmony. F1 mean frequencies distinguish between cross-height vowel pairs in half of the cases. F2 means reliably distinguish between front [ATR] harmony pairs, with [+ATR] vowels having significantly higher F2 means than their [-ATR] counterparts, but do not distinguish back [ATR] harmony pairs. F2 means are also significantly different in six of the eight cross-height vowel pairs, with the [+ATR] mid vowels having the higher of the two means, thus indicating a relatively further front positioning. Bandwidth plays little role in distinguishing cross-height vowel pairs, as mean values are not statistically significant in any of the cases were F1 means are not statistically significant.

Of the secondary acoustic correlates associated with [ATR], spectral flatness is robust for only speaker 4F-J. However, between speakers 1M-Kk, 2M-Ks and 3M-J there are five instances of [-ATR] vowels having significantly steeper slopes than their [+ATR] counterparts. In only two of these cases do the Normalized A1-A2 results agree with the ΔB1 results. Center of gravity fares little better than the measure of spectral flatness. Though all of the [ATR] harmony pairs for speaker 4F-Jc have statistically significant center of gravity means, these results are difficult to interpret since center of gravity values are for the most part lower than F1 means. Only in the case of speaker 2M-Ks do [-ATR] vowels have both statistically higher mean center of gravity values than [+ATR] vowels *and* F1 means. Perceptually, this speaker's vowels have a harsher quality to them, reminiscent of the quality of the vowels associated with the Foodo speakers.

Finally it should be noted that since none of the secondary acoustic correlates of [ATR] are robust for speaker 3M-J's vowels, cross-height vowel pairs are distinguished by F2 mean differences only. Although differences in the quality of the backs vowels are perceptible, very little, if any, qualitative difference can be heard between his high [ɪ] and [e] vowels in isolation.

5.2.4 LuBwisi

Table 5.4: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in LuBwisi

Gray shaded cells indicate vowel pairs not considered in the analysis. Yellow shading indicates a vowel pair which is not distinguished by any acoustic measure A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-B	F1	F2	B1	ΔB1	S.F.	CoG	2M-H	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√+		X	X	X	i ɪ	√-	√+		√-	X	√-
ɪ e	X	√+	X	X	√+	√-	ɪ e	X	X	X	X	X	√-
e ɛ	√-	√+		√-	√+	√-	e ɛ	√-	√+		√-	X	√-
ə ɑ	√-	X	√-	√-	√+	X	ə ɑ	√-	X	√-	√-	√+	√-
o ɔ	√-	X		√-	√+	√-	o ɔ	√-	X		X	X	√-
o ʊ	X	√+	√-	√-	√+	X	o ʊ	√+	√+	X	X	√+	√-
ʊ u	√-	√+		X	√+	X	ʊ u	√-	√+		√-	√+	√-
3F-W	F1	F2	B1	ΔB1	S.F.	CoG	4F-T	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√+		√-	√+	√-	i ɪ	√-	√+		√-	X	√-
ɪ e	X	X	√-	√-	√+	√-	ɪ e	√+	X	X	X	√+	X
e ɛ	√-	√+		√-	X	√-	e ɛ	√-	√+		√-	√+	√-
ə ɑ	√-	X	X	X	X	√-	ə ɑ	√-	X	√-	√-	X	√-
o ɔ	√-	√-		X	X	√-	o ɔ	√-	√-		√-	X	√-
o ʊ	√+	√+	X	X	√+	√+	o ʊ	X	√+	X	X	X	X
ʊ u	√-	√+		√-	√+	√-	ʊ u	√-	X		√-	X	√-
5F-Z	F1	F2	B1	ΔB1	S.F.	CoG							
i ɪ	√-	√+		X	√+	X							
ɪ e	X	X	√-	√-	√+	X							
e ɛ	√-	√+		√-	√+	√-							
ə ɑ	X	X	X	X	X	X							
o ɔ	√-	√+		√-	√+	√-							
o ʊ	X	√+	X	X	X	X							
ʊ u	√-	√+		√+	√-	X							

LuBwisi is a 7-vowel language with the same vowel inventory as Kinande: /i ɪ ɛ ɑ ɔ ʊ u/. [ATR] harmony is also triggered by [+ATR] high vowels which, in addition to raising /ɪ/ and /ʊ/ to /i/ and /u/, respectively, produces [+ATR] variants of [-ATR] mid and low vowels, [e o ə] in the speech of some LuBwisi speakers. The main acoustic correlate of [ATR] in LuBwisi is also F1. With one notable exception, [-ATR] vowels have statistically significantly higher F1 means than their [+ATR] counterparts. This is true whether both members of the [ATR] harmony pair are underlyingly distinct or if one of the members is produced by means of [ATR] harmony. In the case of speaker 5F-Z, [ɑ] and [ə] are not distinguished by F1 mean differences, nor are they distinguished by any other acoustic correlate for that matter (as highlighted in yellow.) These results were not anticipated from the account of [ATR] harmony in LuBwisi as found in Tabb 2001/2204. According to Tabb, speakers whose [-ATR] mid vowels exhibit [+ATR] allophones also have a raised variant of /ɑ/. Lastly, F1 fails to distinguish cross-height vowel pairs in most cases (7 of 10).

F2 mean differences consistently distinguish front [ATR] harmony pairs, with [+ATR] front vowels having statistically significantly higher F2 means than their [-ATR] counterparts, but are again inconsistent for back vowels. In none of the cases are [ɑ] and [ə] distinguished by F2 mean differences. F2 mean differences do distinguish back cross-height pairs, with [+ATR] mid vowels having statistically significantly higher F2 means than [-ATR] high vowels. Note that it is only F2 mean differences which distinguish [ʊ] and [o] for both female speakers. On the other hand, F2 means in the front cross-height pairs [ɪ] and [o] tend not to be significantly different.

In LuBwisi, all of the secondary acoustic correlates of [ATR] make a contribution in varying ways. Bandwidth only occasionally distinguishes cross-height vowel pairs (3 of 10 cases only), with the [-ATR] vowel having the statistically wider bandwidth in those cases in which it does. Note that for the two speakers (1M-B and 5F-Z) whose high front vowels were not distinguished by differences in center of gravity mean values that the [+ATR] vowel had especially high values. ΔB1 results for cross-height vowels are the same as the observed B1 results. Both ΔB1 and Normalized A1-A2 differences, though not consistent across speakers, do distinguish all [ATR] harmony vowel pairs whether they consist of high, mid, low, front or back vowel pairs. ΔB1 out performs Normalized A1-A2 in that there are more [ATR] harmony pairs with statistically significantly different ΔB1 means. On the other hand, there are more cross-height vowel pairs with statistically significantly different Normalized A1-A2 means than either ΔB1 means or observed B1 means. This raises the question of how reliable the normalized measure is in these cases. Nonetheless, for those [ATR] harmony pairs in which Normalized A1-A2 and ΔB1 means are both statistically different, the results compliment each other. This includes even the exceptional case of the high back vowels of speaker 5F-Z where the [+ATR] vowel of the pair always has the significantly steeper slope (or higher ΔB1 mean.)

Center of gravity differences are distributed in several different ways among [ATR] harmony pairs. First, either all [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts or only mid vowel pairs did. In the former case, the speakers split again into two camps, those whose center of gravity mean values are at or well below F1 values and those whose center of gravity mean values are robustly higher than F1 values. Second, in those cases where center of gravity mean differences are significantly different only for mid vowel pairs, center of gravity values are consistently and robustly higher than F1 values for all vowels, rendering especially high center of gravity values for [+ATR] high vowels.

The net result in LuBwisi is that while the primary acoustic correlates of [ATR] (i.e., the vowel formants) are consistent across speakers, the secondary acoustic correlates are not. If presented only with the acoustic data for speakers 1M-B and 5F-Z, one might argue for a case of height harmony in which the vowels are all articulated in a way that produces high center of gravity levels vis-à-vis F1 values. Any differences between height two and three vowels and between low vowels are negligible or non-existent.

On the other hand, if presented only with the acoustic data for speakers 3F-W and 4F-T, one might conceivably argue for a case of [ATR] harmony that is essentially cross-height in nature. The acoustics of speaker 3F-W's vowel system parallels that of Foodo speakers in most ways: [ATR] harmony pairs distinguished by F1 and F2, B1 which distinguishes front cross-height vowels, and center of gravity mean values which are robustly higher than F1, but in which [-ATR] center of gravity mean values are even more robustly higher than F1 than their [+ATR] counterparts. There is but one important difference between the vowels of speaker 3F-W and those of the Foodo speakers: the vowels of LuBwisi are a part of a phonological 7-vowel system but those of Foodo are a part of a phonological 9-vowel system. This a critical point to which we will return to after the language summaries.

5.2.5 Ekiti (and Mọba)

Table 5.5: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Ekiti and Mọba

Gray shaded cells indicate vowel pairs not considered in the analysis. Yellow shading indicates a vowel pair which is not distinguished by any acoustic measure. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-A	F1	F2	B1	ΔB1	S.F.	CoG	2M-M	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	X		X	X	X	i ɪ	√-	√+		√-	X	√-
ɪ e	√+	X	X	X	X	X	ɪ e	X	X	X	X	X	X
e ɛ	√-	√+		X	X	√-	e ɛ	√-	√+		√-	√+	X
o ɔ	√-	√-		√-	√+	√-	o ɔ	√-	X		√-	X	√-
o ʊ	X	X	X	X	X	X	o ʊ	√+	√+	X	X	X	X
ʊ u	√-	√+		√-	X	√-	ʊ u	√-	√+		√+	X	√-
3F-F	F1	F2	B1	ΔB1	S.F.	CoG	4F-N (Mọba)	F1	F2	B1	ΔB1	S.F.	CoG
i ɪ	√-	√-		√-	X	√-	i ɪ	√-	X		X	X	X
ɪ e	√-	X	√-	√-	√+	√-	ɪ e	√+	√-		√+		√+
e ɛ	√-	√+		X	X	√-	e ɛ	√-	√+		X	X	√-
o ɔ	√-	√-		√-	√+	√-	o ɔ	√-	√-		√-	X	√-
o ʊ	√-	√+	√-	√-	√+	X	o ʊ	√+	√-		√-		√+
ʊ u	√-	X		√-	X	√-	ʊ u	X	X		X	X	X

Ekiti and Mọba are Yoruba dialects with the following 7-vowel inventory: /i e ɛ ɑ ɔ o u/. [ATR] harmony is triggered by [-ATR] vowels, including /a/. In the case of Ekiti, [-ATR] vowels produce high vowel variants [ɪ ʊ]. The main and only reliable acoustic correlate of [ATR] in Ekiti, as well as in Mọba, is F1: [-ATR] vowels have statistically significantly higher F1 means than their [+ATR] counterparts. F2 mean differences also distinguish some [ATR] harmony pairs in Ekiti, but not in a consistent manner. While F2 means are significantly higher for the front [+ATR] mid vowels than their [-ATR] counterparts for all three speakers, results for the front high vowels are mixed: F2 mean differences are not significant for 1M-A, the F2 mean for [+ATR] [i] is significantly higher than [-ATR] [ɪ] for 2M-M but significantly lower for 3F-F.

The secondary acoustic correlates of [ATR] contribute little to none in differentiating either [ATR] harmony or cross-height [ATR] harmony pairs of the male Ekiti speakers as well as the Mọba speaker. Center of gravity mean values, in particular, are all significantly lower than F1 means for these three speakers. Additionally, each of the male speakers has one cross-height vowel pair (highlighted with yellow shading) that is not distinguished by any acoustic measure. It would appear that for these speakers with this particular dataset, that there is no measurable and statistically verifiable phonetic difference between these vowels. Perhaps with a larger and more varied database, these vowel pairs would pattern like the other vowel pair of these speakers, having significantly different F1 means.

To what extent speakers 1M-A and 2M-M are representative of Ekiti speakers is unknown as the third Ekiti speaker, 3F-F, presents a somewhat different picture of Ekiti: bandwidth differences, spectral flatness and center of gravity present systematic differences in the cross-height pairs. The differences between bandwidths of cross-height vowels, for example, are not unlike those seen for some Foodo or Ikposo speakers, although [+ATR] mid vowels do have overall smaller B1 means than in Ikposo and Foodo than for this Ekiti speaker. Additionally, ΔB1 mean differences are statistically significant for all vowel pairs except [e] and [ɛ]. On the other hand, the center of gravity mean for [-ATR] [ɪ] is still some 50 Hz lower than the lowest mean for this vowel quality in Foodo. More importantly, the center of gravity mean values for other [–round][-ATR] vowels are significantly lower than F1 mean values. In other words, the [–round][-ATR] vowels do not have uniformly high center of gravity mean values as they do in Foodo. This is a similar pattern to that found in Ikposo. These findings suggest that while not necessarily as robust, the acoustic profile for speaker 3F-F has similarities to the acoustic profiles for both Ikposo and Foodo speakers.

While the research design for this study was not the same as the Przezdziecki 2005 study of Yoruba dialects, it is not beyond reason to conclude that the results for the Mọba speaker support the findings of Przezdziecki for Mọba: the increase in F1 frequency of the underlying high front vowel is an effect of co-articulation. The results for the two male Ekiti speakers may also support his finding for Akurẹ, which also has [-ATR] high vowel allophones. None of the secondary acoustic measures are especially robust for these two speakers, especially noticeable in the front high [ATR] pair for speaker 1M-A where only F1 mean differences are statistically significant.

However, one major difference between the designs of our studies is the attention given to cross-height vowels, (which Przezdziecki does not discuss). It is precisely at this point that the differences in the acoustic behaviors of the vowels of the two male Ekiti speakers differ from that of the female speaker. As pointed out above, both of the male speakers have a pair of cross-height vowels which are not distinguished by any acoustic measure. Impressionistically, I can hear qualitative differences between some of the tokens of these cross-height vowel pairs but not others.

Contrary to the male speakers, the cross-height pairs for the female speaker are both distinguished by F1 mean differences. However, as was seen earlier in Figure 4.21, there is some F1 and F2 overlap at the margins of the front vowel pair. The first token of the [e] in *ode*, for example, has an F1 of 417 Hz and an F2 of 2352 Hz. The seventh token of the [ɪ] in *itɔ* also has an F1 of 417 Hz and an F2 of 2355 Hz. These two tokens of these vowels would appear to overlap in acoustic space. However, their F1 bandwidth and center of gravity measures are as follows: [e] 28 Hz and 505 Hz, [ɪ] 51 Hz and 777 Hz. The values of F1 bandwidth and center of gravity for these two tokens are similar to the kinds of measures we find for Foodo. Impressionistically, these differences in measurements translate into the [ɪ] sounding more constricted than the [e]. This finding suggests that at least for some speakers of Ekiti we must recognize that acoustic measures other than F1 distinguish overlapping cross-height vowels and that if those measures are available to cross-height vowels, then they are also presumably available for distinguishing [ATR] harmony vowel pairs.

5.2.6 Ifè

Table 5.6: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Ifè

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

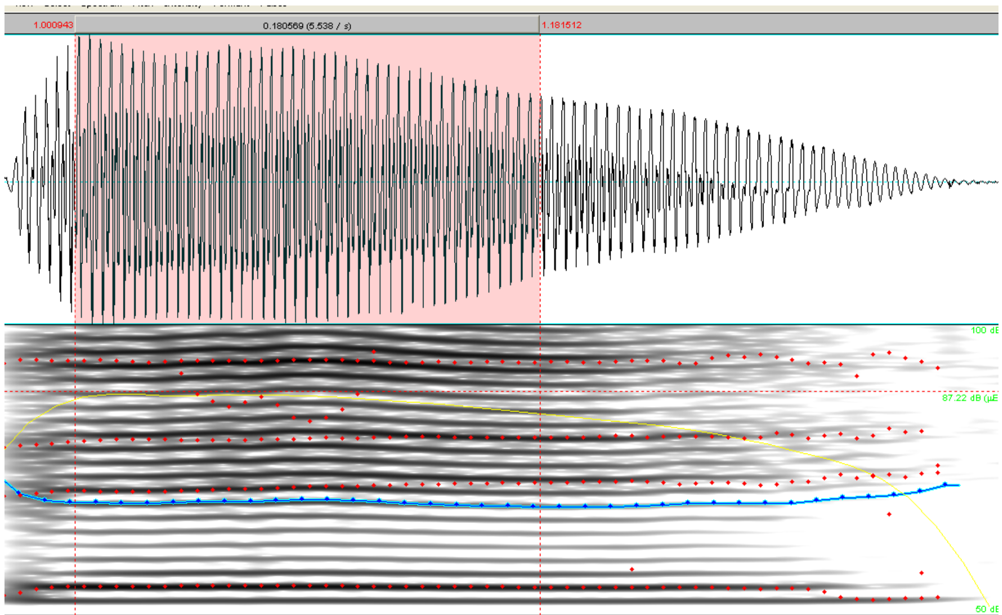
1M-Kv	F1	F2	ΔB1	S.F.	CoG	2M-Y	F1	F2	ΔB1	S.F.	CoG
i e	√	√				i e	√	√			
e ɛ	√-	√+	X	X	√-	e ɛ	√-	√+	√-	√+	√-
o ɔ	√-	√-	√-	X	√-	o ɔ	√-	√-	√-	√+	√-
o u	√	√				o u	√	√			
3M-K	F1	F2	ΔB1	S.F.	CoG	4F-I	F1	F2	ΔB1	S.F.	CoG
i e	√	√				i e	√	√			
e ɛ	√-	√+	X	X	√-	e ɛ	√-	√+	√-	√+	√-
o ɔ	√-	√-	√-	√+	√-	o ɔ	√-	√-	√-	√+	√-
o u	√	√				o u	√	√			
5F-M	F1	F2	ΔB1	S.F.	CoG						
i e	√	√									
e ɛ	√-	√+	√-	√+	X						
o ɔ	√-	√-	√-	X	√-						
o u	√	√									

Ifè is a 7-vowel language with the following inventory: /i e ɛ ɑ ɔ o u/. While [ATR] harmony may be understood as an instance of mid-vowel collocation restrictions within the root, there was evidence presented in §2.2.2.2 of coalescent [-ATR] harmony in Ifè. As is the case for the languages with nine or ten surface vowels, the main acoustic correlate of [ATR] in Ifè is F1. Unlike any of the other languages in this study, though, Ifè presents a consistently uniform and symmetrical picture of the use of acoustic space across speakers. F2 mean differences are statistically significant for both [ATR] harmony pairs and cross-height vowel pairs. Note that in this case, and the rest of the 7-vowel languages, that “cross-height” refers to height 1 and 2 and not height 2 and 3 vowels. Among front vowels, each vowel has a significantly lower F2 mean than the F2 mean of the vowel at the height above it: /i/>/e/>/ɛ/. The order is reversed for back vowels (/a/ is not considered), i.e. /u/</o/</ɔ/, with each vowel having a significantly higher F2 mean than the F2 mean of the vowel at the height above it.

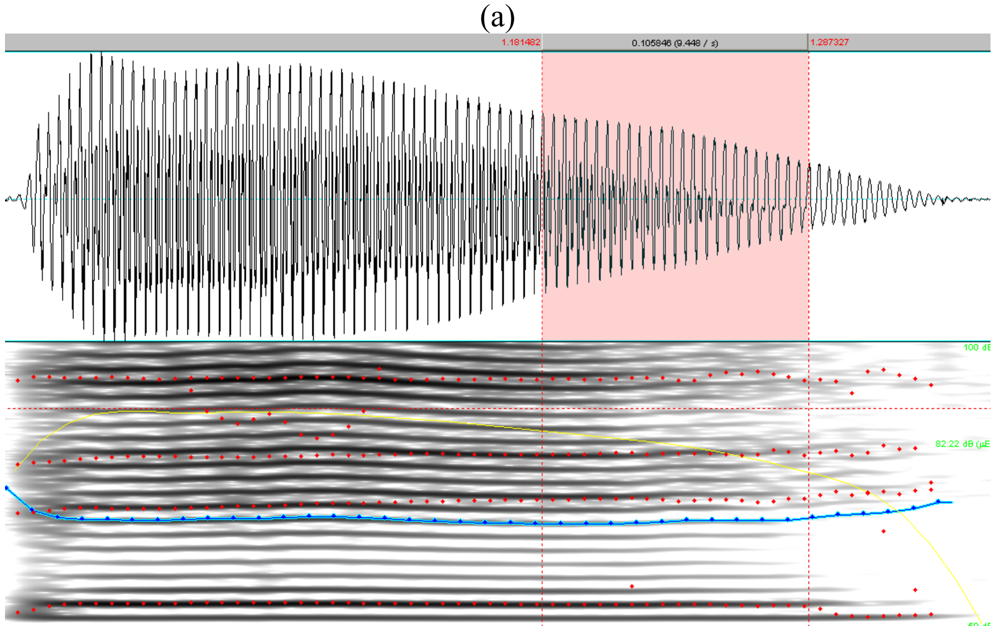
As for the secondary acoustic correlates, [+ATR] mid vowels tend to have significantly higher Normalized A1-A2 means, suggesting steeper spectral slopes for the measure of spectral flatness, than their [-ATR] counterparts. The effect is not consistent across speakers. No statistical analysis of observed F1 bandwidth was possible for Ifè since there are no vowels overlapping in F1, but the ΔB1 measurement proves to be slightly more consistent than the Normalized A1-A2 results, with [-ATR] vowels having statistically significantly greater displacement from the Fant 1972 predicted values than their [+ATR] counterparts. Center of gravity means of [-ATR] vowels are overall significantly higher than their [+ATR] counterparts. Two of the speakers, however, have center of gravity means for [-round][-ATR] vowels which are either significantly lower or not significantly different from F1 means, while one of the female speakers, 4F-I, had center of gravity mean values in the same Hz range as Foodo vowels.

One important note on center of gravity in Ifè pertains to the syllable lengthening effect in Yoruba related languages mentioned in §3.1. Ifè, like other Edekiri languages, lengthens prepausal vowels. Coupled with length, there is generally also a drop in amplitude and a more "breathy" quality to the vowel accompanying the drop of amplitude. This "breathy" quality translates acoustically into a drop of center of gravity without any appreciable changes in vowel formants. For example, in a token of [e] for speaker 4F-I the first two-thirds of the vowel (Figure 5.1a) has an F1of 484 Hz and a center of gravity of 620 Hz. The last third of the vowel, measured to the point where the middle harmonics begin to fade (Figure 5.1b), has an F1 of 458 Hz and a center of gravity of 446 Hz. The center of gravity value of the vowel drops from 136 Hz *above* F1 to 12 Hz *below* F1. The drop in center of gravity corresponds to the drop in amplitude (marked by the yellow line).

Compare these results to a token of Foodo [e] spoken by 4F-A (Figure 5.2). Formants and fundamental frequency are equally stable but there is no appreciable drop in amplitude towards the end of the vowel. In the first two-thirds of the vowel (Figure 5.2a), F1 is 618 Hz and center of gravity 645 Hz. During the last third of the vowel (Figure 5.2b), F1 measures 605 Hz and center of gravity 633 Hz. In both cases, center of gravity is 27-28 Hz above F1. In other words, while center of gravity is most likely a distinctive feature associated with vowel quality in Foodo, in Ifè, it is probably more accurately a phrasal feature.

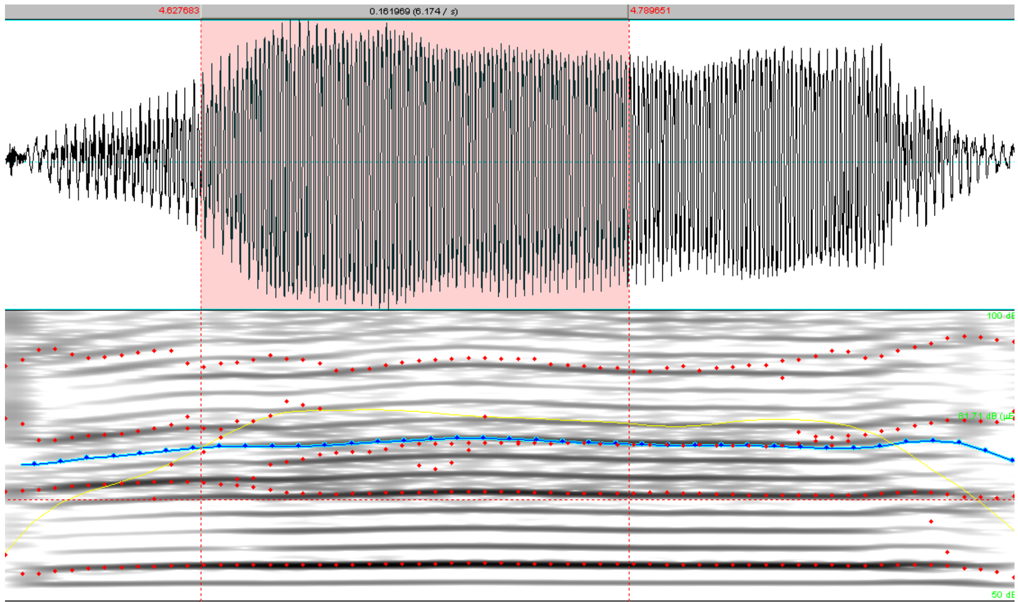


(a)

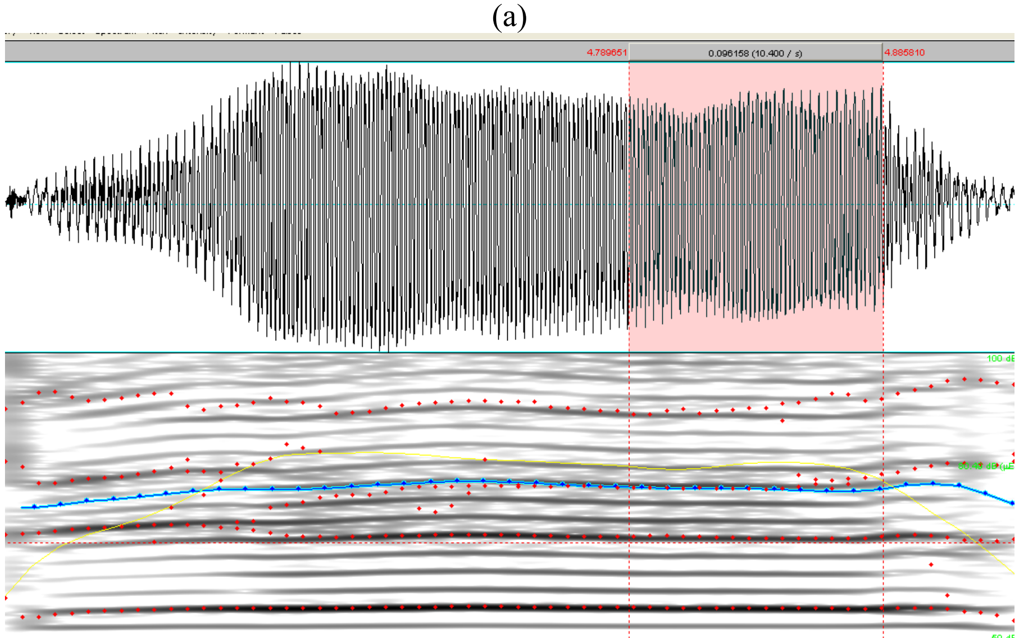


(b)

Figure 5.1: Waveform and Narrow Spectrogram Display of a Token of [e] for Ifè speaker 4F-I. Red dotted lines=formant tracks, blue line=pitch track, yellow line=amplitude track. Highlighted area of the waveform=area measured for F1 and center of gravity.



(a)



(b)

Figure 5.2: Waveform and Narrow Spectrogram Display of a Token of [e] for Foodo speaker 4F-A. Red dotted lines=formant tracks, blue line=pitch track, yellow line=amplitude track. Highlighted area of the waveform=area measured for F1 and center of gravity.

5.2.7 Dibole

Table 5.7: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Dibole

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1F-MN	F1	F2	ΔB1	S.F.	CoG	2F-F	F1	F2	ΔB1	S.F.	CoG
i e	√	√				i e	√	√			
e ɛ	√-	√+	X	X	√-	e ɛ	√-	X	√-	X	√-
o ɔ	√-	√-	√-	X	√-	o ɔ	√-	√-	X	X	√-
o u	√	√				o u	√	√			
3F-S	F1	F2	ΔB1	S.F.	CoG	4M-C	F1	F2	ΔB1	S.F.	CoG
i e	√	√				i e	√	X			
e ɛ	√-	X	X	X	√-	e ɛ	√-	√+	√-	√+	√-
o ɔ	√-	√-	X	X	√-	o ɔ	√-	√-	X	X	√-
o u	√	√				o u	√	√			
5M-L	F1	F2	ΔB1	S.F.	CoG						
i e	√	X									
e ɛ	√-	√+	√-	X	√-						
o ɔ	√-	√-	√-	X	√-						
o u	√	X									

Dibole is a 7-vowel language with the following inventory: /i e ɛ ɑ ɔ o u/. Dibole is analyzed as having rightward spread of [-ATR] that includes final vowel *–e*.[52] The main acoustic correlate of [ATR] in Dibole is F1 with [-ATR] mid vowels having significantly higher F1 means than their [+ATR] counterparts. F2 does not consistently distinguish either [ATR] or cross-height pairs.

[52] Note that Leitch 1996 employs privative [RTR] rather than [-ATR] in his analysis of Dibole, Mbosi and other Bantu C languages.

Of the secondary acoustic correlates associated with [ATR], spectral flatness plays virtually no role in distinguishing [ATR] harmony pairs in these data. No statistical analysis of bandwidth was conducted for Dibole vowels since none overlap in F1. However, in §4.3.7 we saw a tendency for all vowels to have higher bandwidth values than the Fant 1972 predicted values. The ΔB1 measure, however, reveals that means are statistically significantly different in five of the ten possible [ATR] harmony pairs with [-ATR] vowels having the greater displacement from predicted values than their [+ATR] counterparts. Center of gravity means, on the other hand, are consistently statistically significantly different within [ATR] harmony pairs. Three of the speakers had only moderate differences of center of gravity values vis-à-vis F1 means. But one female speaker, 3F-S, had center of gravity values approaching those of the Foodo data. Of particular interest is her front [ATR] harmony pair [e ɛ] which has center of gravity and F1 values comparable to the male Foodo speakers. Like Foodo, the measured vowels were not in prepausal position, and thus center of gravity and F1 values are consistent across the vowels.

In §4.2.7 it was shown that the F1 mean values of [e] and [a] differed significantly when these vowels are followed by a [+ATR] final vowel from when they were followed by [a]. This was true for all five speakers. When secondary acoustic correlates for these vowels are considered, specifically Normalized A1-A2 and center of gravity, no discernable pattern emerges. On the surface, it appears that these significant results are due perhaps to a kind of co-articulation effect like such that was proposed for Yoruba by Przezdzieki (2005). When the F1 bandwidths and ΔB1 differences are considered for [e] and [a] depending on the environment in which they occur, an interesting pattern emerges. Table 5.8 compiles the results of one-way ANOVA run for [e] and [a] when their B1 and ΔB1 means are dependent factors of the [ATR] value of the vowel in V_2 position.

Table 5.8: One-Way ANOVA Results of B1 and ΔB1 for [e] and [a] based on the [ATR] value of V_2

Shaded cells indicate B1 mean differences are not statistically significantly. For those cases where B1 means and ΔB1 means are statistically significantly different, $p<.05$. '√' indicates the ΔB1 mean of a vowel before a [+ATR] vowel in V_2 position is statistically significantly lower than before a [-ATR] vowel in V_2 position. '±' indicates which [ATR] value is lower. 'X' indicates ΔB1 mean differences are not statistically significant.

Speaker	B1 Environment for [e]		ΔB1	B1Environment for [a]		ΔB1
	before [e]	before [a]		before [i]	before [a]	
1F-MN	33	24	X	79	114	√+
2F-F	17	35	√+	75	99	√-
3F-S	29	53	√+	107	96	X
4M-C	52	44	X	90	80	X
5M-L	37	58	√+	84	100	X

In three cases, the B1 mean for [e] before an [e] in V_2 position is statistically significantly lower than the B1 mean for [e] before an [a] in V_2 position. The ΔB1 mean differences agree with the B1 results, with [e] before an [e] in V_2 position having statistically significantly lower ΔB1 means than [e] before an [a] in V_2 position. The results for [a] before [i] in V_2 position are mixed and therefore inconclusive. In addition, speaker 1F-MN had [e] tokens with the greatest F1 mean spread (F1 mean of 372 Hz for [e] before an [e] and F1 mean of 496 Hz for [e] before an [a].) However, her [e] tokens do not have statistically significantly different B1 or ΔB1 means. Neither do these tokens have statistically significantly different center of gravity means. It seems unlikely that anything but a coarticulation effect is contributing to the statistically significant mean differences in F1 in this speaker's [e] tokens.

5.2.8 Mbosi

Table 5.9: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Mbosi

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-C	F1	F2	ΔB1	S.F.	CoG	2M-Le	F1	F2	ΔB1	S.F.	CoG
i e	√	√				i e	√	√			
e ɛ	√-	√+	√-	X	√-	e ɛ	√-	√+	√-	√+	√-
o ɔ	√-	√-	X	√+	√-	o ɔ	√-	X	√-	X	√-
o u	√	√				o u	√	X			
3M-O	F1	F2	ΔB1	S.F.	CoG	4F-Ly	F1	F2	ΔB1	S.F.	CoG
i e	√	√				i e	√	√			
e ɛ	√-	X	√-	X	X	e ɛ	√-	X	√-	√+	√-
o ɔ	√-	X	√-	X	√-	o ɔ	√-	√+	√-	√+	√-
o u	√	√				o u	√	√			
5F-M	F1	F2	ΔB1	S.F.	CoG						
i e	√	√									
e ɛ	√-	X	√-	√+	√-						
o ɔ	√-	X	√-	X	√-						
o u	√	√									

Mbosi is also a 7-vowel language with the inventory: /i e ɛ ɑ ɔ o u/. Mbosi is analyzed as having as having lexical [-ATR] harmony plus final *–e* (along with post-lexical leftward spread). The main acoustic correlate of [ATR] in Mbosi is also F1 with

[-ATR] mid vowels having significantly higher F1 means than their [+ATR] counterparts. F2, as usual, does not consistently distinguish either [ATR] or cross-height pairs.

Of the secondary acoustic correlates associated with [ATR], the Normalized A1-A2 means (the measure of spectral flatness) are significantly different in just half the [ATR] harmony pairs, but in those cases, the [+ATR] vowel always has the statistically significantly higher mean, indicating a steeper spectral slope than [-ATR] vowels. Again no statistical analysis of bandwidth was conducted for Mbosi vowels since none overlap in F1. However, in §4.3.8 a tendency for the [+ATR] mid vowels to have B1 means at or below the predicted Fant values was noted. [-ATR] mid vowels B1 means, on the other hand, were up to 50-80 Hz higher than their [+ATR] counterparts. ΔB1 as a measurement is robust in Mbosi as mean values for [ATR] pairs are statistically significantly different in all but one case – the back mid vowels of speaker 1M-C. In every case, [-ATR] mean values are significantly greater than the mean values of [+ATR] counterparts.

Center of gravity mean differences across [ATR] harmony pairs are largely statistically significant. But as noted in §4.5.8, the male speakers had center of gravity values consistently lower than F1 values while the females had center of gravity values consistently higher than F1 values. There is again, specifically, one female speaker (4F-Ly) whose center of gravity values for all vowels are comparable to those of Foodo.

5.2.9 Mbonge

Table 5.10: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Mbonge

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-Jo	F1	F2	ΔB1	S.F.	CoG	2M-J	F1	F2	ΔB1	S.F.	CoG
i e	√	X				i e	√	X			
e ɛ	√-	√+	√-	√+	√-	e ɛ	√-	√+	√-	X	√-
o ɔ	√-	X	√-	X	√-	o ɔ	√-	X	X	X	√-
o u	√	X				o u	√	X			
3M-P	F1	F2	ΔB1	S.F.	CoG	4F-J	F1	F2	ΔB1	S.F.	CoG
i e	X	√				i e	√	√			
e ɛ	√-	√+	√-	X	√-	e ɛ	√-	√+	√-	√+	X
o ɔ	√-	X	√-	X	X	o ɔ	√-	√-	√-	√+	√-
o u	√	X				o u	√	√			
5F-B	F1	F2	ΔB1	S.F.	CoG						
i e	√	X									
e ɛ	√-	√+	√-	X	X						
o ɔ	√-	X	√-	X	X						
o u	√	X									

Mbonge is also a 7-vowel language whose vowel inventory has been stated to be /i e ɛ ɑ ɔ o u/ by D. Friesen (2002). The main correlate of [ATR] in Mbonge is F1: [-ATR] mid vowels have significantly higher F1 means than their [+ATR] counterparts. F2 does not consistently distinguish either [ATR] or cross-height vowel pairs.

Of the secondary acoustic correlates of [ATR], neither the measure of spectral flatness nor center of gravity contributes much to distinguishing [ATR] harmony pairs.

Normalized A1-A2, the measure of spectral flatness, has statistically significant mean difference in only three of the ten [ATR] harmony pairs in the data set. Center of gravity fares slightly better (six of ten) but has values largely below F1 for all speakers except speaker 5F-B. However, neither center of gravity mean differences nor Normalized A1-A2 mean differences is statistically significant for the [ATR] harmony pairs in the speech of speaker 5F-B.

In contrast to Normalized A1-A2 and center of gravity, a clear pattern emerges from the analysis of ΔB1. As in Mbosi, all but one of the mid-vowel [ATR] pairs for the Mbonge speakers present statistically significantly different means. In every case where the pairs have statistically significant mean differences, the [-ATR] vowel mean is greater than that of its [+ATR] counterpart.

5.2.10 Londo

Table 5.11: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Londo

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-CE	F1	F2	ΔB1	S.F.	CoG	2M-W	F1	F2	ΔB1	S.F.	CoG
i e	√	X				i e	√	√			
e ɛ	√-	√+	√-		√-	e ɛ	√-	√+	√-	X	√-
o ɔ	√-	X	√-		√-	o ɔ	√-	√-	√-	√+	√-
o u	√	X				o u	√	√			
3M-I	F1	F2	ΔB1	S.F.	CoG	4F-M	F1	F2	ΔB1	S.F.	CoG
i e	√	√				i e	√	√			
e ɛ	√-	√+	X	X	√-	e ɛ	√-	X	√-	√-	√-
o ɔ	√-	√-	√-	X	√-	o ɔ	√-	X	√-	√-	√-
o u	√	X				o u	√	X			
5F-H	F1	F2	ΔB1	S.F.	CoG						
i e	√	√									
e ɛ	√-	√+	√-	√-	√-						
o ɔ	√-	X	√-	√-	√-						
o u	√	√									

Londo is also a 7-vowel language whose vowel inventory has alternatively been reported as /i e ɛ ɑ ɔ o u/ (D. Friesen 2002) or as /i ɪ ɛ ɑ ɔ ʊ u/ (Kuperus 1985). Specifically, D. Friesen claims the height two vowels of all Oroko dialects are [-high, +ATR], but Kuperus claims the height two vowels of Londo are underlyingly [+high, -ATR]. For further details, see §2.2.1.1.1.

As in Mbonge, the main correlate of [ATR] in Londo is F1: [-ATR] mid vowels have significantly higher F1 means than their [+ATR] counterparts. F2 does not consistently distinguish either [ATR] or cross-height vowel pairs.

Some of the secondary acoustic correlates are difficult to interpret. Normalized A1-A2 results are mixed with [-ATR] vowels having statistically significantly higher mean values than [+ATR] vowels in four of the five cases where means are significantly different. These results would lead to the conclusion that [-ATR] vowels have steeper spectral slopes than [+ATR] vowels. Center of gravity mean differences, on the other hand, are consistent across speakers in that the [-ATR] vowels have significantly higher center of gravity means than their [+ATR] counterparts. However, in four of five speakers, the center of gravity means are all significantly lower than F1 means. In the fifth speaker, 5F-H, again a female, center of gravity values mirror those of Foodo speakers, with especially high values of center of gravity for [–round][-ATR] vowels.

In contrast to the Normalized A1-A2 results, ΔB1 results are consistent and as expected: all pairs but one (the front pair for speaker 3M-I) have [-ATR] mid vowels with statistically significantly greater ΔB1 means than their [+ATR] counterparts. These results are true even for speaker 1M-CE whose data were not suitable to spectral analysis involving direct observation of the harmonic structure. As was seen in Figure 4.73 and will be seen in Table 5.16, this speaker's observed bandwidths and ΔB1 results do not differ in any substantial way from the other four Londo speakers. It will be argued below that for several reasons ΔB1 is a more reliable measure of spectral timbre than the normalized measurement.

5.2.11 Tuwuli

Table 5.12: Summary of the Statistical Significance of Acoustic Correlates of [ATR] in Tuwuli

Shaded cells indicate vowel pairs not considered in the analysis. A '√' indicates a statistically significant difference in mean values; 'X' indicates no significant difference. '±' indicates which [ATR] value is higher. S.F.=Spectral Flatness, CoG=Center of Gravity.

1M-J	F1	F2	ΔB1	S.F.	CoG	2M-An	F1	F2	ΔB1	S.F.	CoG
i e	√	X				i e	√	√			
e ɛ	√-	√+	√-	X	√-	e ɛ	√-	√+	√-	X	√-
o ɔ	√-	√-	X	√-	√-	o ɔ	√-	X	√-	X	√-
o u	√	√				o u	√	X			
3M-A	F1	F2	ΔB1	S.F.	CoG	4F-F	F1	F2	ΔB1	S.F.	CoG
i e	√	X				i e	√	√			
e ɛ	√-	√+	X	X	√-	e ɛ	√-	√+	X	√-	X
o ɔ	√-	√-	√-	X	√-	o ɔ	√-	√-	√-	√-	√-
o u	√	√				o u	√	X			
5F-T	F1	F2	ΔB1	S.F.	CoG						
i e	√	X									
e ɛ	√-	√+	√-	X	√-						
o ɔ	√-	√-	√-	X	√-						
o u	√	X									

Tuwuli is also a 7-vowel language with the inventory: /i e ɛ ɑ ɔ o u/. It has been reported to have anticipatory [+ATR] harmony (Harley 2005). However, as discussed in §2.1.3, there is a stronger case for [-ATR] harmony in Tuwuli.

As in every other language in this study, the main correlate of [ATR] in Tuwuli is F1: [-ATR] mid vowels have significantly higher F1 means than their [+ATR] counterparts. F2 mean differences are largely statistically significant. For those pairs which have statistically significant F2 means, front vowels have [+ATR] vowels with higher means and back vowels have [-ATR] vowels with higher means. F2 does not reliably distinguish cross-height vowel pairs.

As was seen in Londo, the Normalized A1-A2 results indicate that [-ATR] vowels have statistically significantly higher mean values than [+ATR] vowels in all three of cases where means are significantly different. These results would again lead to the conclusion that [-ATR] vowels have steeper spectral slopes than [+ATR] vowels in these cases. But as in Londo, center of gravity mean differences are largely statistically significant with [-ATR] vowels having higher means than their [+ATR] counterparts. But in §4.5.11 no discernable pattern emerged of the displacement of center of gravity from F1: one speaker had very high center of gravity means, another had very low ones and two had moderately high means. The final speaker had center of gravity values in the range of Foodo vowels.

The ΔB1 results again provide a more promising picture: [-ATR] mid vowels have statistically significantly different ΔB1 means than their [+ATR] counterparts in seven of ten cases. All speakers have at least one mid-vowel pair with statistically significantly different ΔB1 means.

Table 5.13: Summary Chart of the Acoustic Correlates of the Eleven Study Languages

A legend of diacritics used in the chart may be found below

Vowel System	ATR Type	Language	Family	F1* H.P.	F1* C-H.P.	F2*H.P.	B1* C-H.P.	ΔB1* H.P.	ΔB1* C-H.P	S.F.*H.P.	S.F.* C-H.P.	CoG*H.P.	CoG* C-H.P
9-vowel: iɪeɛ(ə)aɔoʊu	+ATR	Foodo	Kwa	√	X (2/8)	?	√ (6/8)	mid vowels	√ (6/8)	mid vowels reversed Hi	√ (7/8)	√	front vowels
		Ikposo		√	√ front vowels	?	√? (5/10)	mid & low vowels	√?(6/10)	mid vowels reversed Hi	√? (6/10)	mid vowels reversed Hi	reversed
7-vowel: iɪɛaɔʊu[eəo]		Kinande	Bantu J	√	? (4/8)	?	X (1/8)	mid & low vowels	X (2/8)	mid vowels reversed Hi	X (3/8)	mid vowels reversed Hi	1 speaker
		LuBwisi		√	X (3/10)	√?(15/25)	X (3/10)	√ (17/25)	X (3/10)	high, mid & low vowels	√ (7/10)	mid vowels some high	1 speaker
7-vowel: ieɛaɔou[ɪʊ]	-ATR	Ekiti	Edekiri	√	√ (4/6)	?	? (2/6) 1 speaker	mid vowels (4/6)	? (2/6) 1speaker	limited mid (3/6)	? (2/6) 1 speaker	mid vowels some Hi	X (1/6)
7-vowel: ieɛaɔou		Mọba		√	?	?		back mid		none		mid vowels	reversed
		Ifè		√	√	?		√ (8/10)		√?(6/10)		√ (9/10)	
		Dibole	Bantu C	√	√	?		√? (5/10)		X		√	
		Mbosi		√	√	?		√ (9/10)		? (5/10)		√ (9/10)	
		Mbonge	Bantu A	√	√?	?		√ (9/10)		X (3/10)		? (6/10)	
		Londo		√	√	?		√ (9/10)		reversed		√	
		Tuwuli	Kwa	√	√	?		√ (7/10)		reversed		√ (9/10)	

Key:
- H.P. = [ATR] harmony Pairs
- C-H.P. = Cross-Height Pairs
- F1 = First Formant mean
- F2 = Second Formant mean
- B1 = First Formant Bandwidth mean
- CoG = Center of Gravity Mean
- * = Statistically Significant
- √ = Present in all or most cases
- X = Not present in most cases
- ? = Undecided
- S.F. = Spectral Flatness (Normalized A1-A2 mean)
- ΔB1 = Delta B1 (Observed B1 – Predicted B1

5.2.12 Evaluation of the Acoustic Correlates of [ATR]

A summary of the acoustic correlates of the eleven appears in Table 5.13. The chart reiterates each language's family, vowel system and dominant [ATR] feature and then summarizes the results of the following of the acoustic measures presented in Chapter 4 deemed most pertinent: F1 in [ATR] harmony pairs and in cross-height pairs, F2 in [ATR] harmony pairs, F1 bandwidth (B1) in cross-height pairs, ΔB1 (the distance of B1 from the Fant 1972 predicted values) in [ATR] harmony pairs and cross-height pairs, Normalized A1-A2 (the measure of spectral flatness in [ATR] harmony pairs and cross-height pairs, and center of gravity in [ATR] harmony and cross-height pairs. In each cell for the acoustic measures some indication of the strength of the statistical significance of the vowel pair's means is given. For example, in the column headed by F1*H.P. (the statistical significance of F1 means in [ATR] harmony pairs), a '√' mark indicates in this column that all [ATR] pairs have means that are statistically significantly different and that the [ATR] value (in this case [+ATR]) is as anticipated. An 'X' in a particular cell indicates that the mean of that feature is not statistically significant in most cases. For example, in the B1*C-H.P. column, cross-height vowel pairs, [ɪ]-[e] and [ʊ]-[o], tend not to have statistically significantly different B1 means in the Kinande and LuBwisi data. The numbers in parentheses indicate how many pairs of the total possible have statistically significantly different means. A '?' followed by numbers in parentheses indicates that it is uncertain whether the percentage of cases of pairs with statistically significantly different means for that acoustic measure is robust enough to be considered a strong tendency in the language. An example in the

ΔB1*H.P. would be that of Dibole where five of ten possible mid-vowel pairs have ΔB1 means that are statistically significant. Other cases of the use of '?' will be explained below.

Beginning with F1, we can now assess each acoustic measure in terms of its relevance in distinguishing either [ATR] harmony or cross-height vowel pairs. All eleven languages unambiguously differentiate [ATR] harmony pairs via statistically significantly different F1 means. This finding was expected as every acoustic study undertaken thus far on [ATR] harmony in African languages has shown F1 to be the main acoustic correlate of [ATR].

On the other hand, the importance of F1 in distinguishing cross-height harmony pairs in the five languages with nine or ten surface vowels is language specific. In Ikposo, F1 mean differences reliably distinguish front vowels but not back vowels. In Kinande, both front and back vowels have statistically significantly different F1 means in just half of the cases.

However, in Foodo and LuBwisi, the tendency is for F1 mean differences to not be statistically significantly different. Thus F1 fails for the most part to distinguish any height differences between degree 2 and 3 vowels. Note that degree 3 vowels are [+ATR] /e o/ in Foodo, but [-ATR] /ɛ ɔ/ in LuBwisi. If F1 were the sole reliable acoustic measure of vowel quality then we would perhaps have evidence of the merger of heights 2 and 3 vowels in Foodo. But we know this not to be the case from secondary acoustic measures such as center of gravity or F1 bandwidth mean differences. The tendency in LuBwisi for the [+ATR] allophones of degree 3 vowels /ɛ ɔ/ to have F1 means which are not statistically significantly different from degree 2 vowels /ɪ ʊ/ raises another question. Do we in fact have evidence that degree 3 vowels are raising to degree 2 vowels, giving support to claims made in Clements 1992 that an oral feature (such as [open]) rather than [ATR] better explains the harmonic process? Again, the answer will have to lie in the secondary acoustic correlates of [ATR] to decide this issue.

We will return to the importance of F1 in distinguishing cross-height vowels in the four-height seven-vowel systems with mid-vowel harmony when considering more closely the question of whether it is possible to know definitively whether a degree two vowel is [+ATR] [e o] or [-ATR] [ɪ ʊ]. At this point it is simply noted that F1 mean differences consistently distinguish degree 1 and degree 2 vowels.

Contrary to F1, F2 plays an ambiguous role in distinguishing [ATR] harmony pairs in the eleven languages. These results are also expected from the review of previous acoustic studies of languages with [ATR] harmony. In the chart, a '?' mark in a cell of F2*H.P. column marks this ambiguity and is there either because there are several to many cases where F2 mean differences are not statistically significant or because the [ATR] value with the highest F2 mean is not consistent across speakers. With the exception of Ifè, where F2 means are statistically significantly different for all vowel qualities for every speaker, the rest of the languages have one or more speakers with at least one [ATR] pair that is not distinguished by F2 mean differences. For pairs that do have significant F2 mean differences, the general tendency is for front vowels to have [+ATR] vowels with significantly higher F2 means than their [-ATR] counterparts, but for the inverse to be true for back vowels, [-ATR] vowels having significantly higher F2 means than their [+ATR] counterparts. The only exceptional language is LuBwisi where 15 of the 16 [ATR] pairs with statistically significant F2 means had a [+ATR] with the higher mean.

Direct observation of F1 bandwidth could only be conducted for those languages with vowels F1 values that overlapped or were very close. B1 under these conditions fares best in the two languages with contrastive [-ATR] high and [+ATR] mid vowels. Of the six cross-height pairs that have significantly different B1 means in Foodo, four of these had F1 means that were not statistically significantly different. In Ikposo, three back cross-height pairs had F1 means that were not statistically significantly different. B1 mean differences are significant in each of these cases.

B1 does not play as consistently a role in differentiating cross-height pairs in the three 7-vowel languages with nine or ten surface vowels. Although there is one case in which B1 mean differences are statistically significant, the F1 mean differences are also statistically significant. In other words, none of the four cases where F1 means are not significantly different are B1 mean differences statistically significant. B1 in LuBwisi while not robust does fare a bit better. B1 mean differences are statistically significant for three of the seven cross-height vowel pairs whose F1 means are not. In the case of Ekiti, one speaker had cross-height vowels with statistically significant B1 means. These vowels also had statistically significantly distinct F1 means.

As for the cross-height vowels for the languages with nine or ten surface vowels, ΔB1 mean differences mirror the results of observed B1, so the same observations are true of it as are of B1.

ΔB1 and the Normalized A1-A2 measure will be evaluated together for [ATR] harmony and cross-height pairs. Tables 14 and 15 summarize the comparison of results of ΔB1 and the Normalized A1-A2 for the languages with nine or ten surface vowels (Table 14) and for the languages with seven surface vowels (Table 15).

Table 14: ΔB1 and the Normalized A1-A2 Compared for 9-(10-) Vowel Languages

Numbers indicate number of pairs across languages. "X" indicates mean differences for pairs are not statistically significant. '√-' indicates [-ATR] has a significantly higher mean than [+ATR]. '√+' indicates the contrary. Yellow shading indicates expected agreement between ΔB1 and Normalized A1-A2.

ΔB1 \ Normalized A1-A2	X	√+	√-
X	35	14	3
√-	36	41	3
√+	3	0	5

Table 15: ΔB1 and the Normalized A1-A2 Compared for 7-Vowel Languages

Numbers indicate number of pairs across languages. "X" indicates mean differences for pairs are not statistically significant. '√-' indicates [-ATR] has a significantly higher mean than [+ATR]. '√+' indicates the contrary. Yellow shading indicates expected agreement between ΔB1 and Normalized A1-A2

ΔB1 \ Normalized A1-A2	X	√+	√-
X	11	1	2
√-	26	15	5
√+	0	0	0

For the languages with nine or ten surface vowels, a total of 140 possible vowel pairs (either [ATR] or cross-height) were analyzed to determine the statistical significance of ΔB1 and Normalized A1-A2 mean differences. In 57% of the pairs (81/140), ΔB1 and Normalized A1-A2 agree as to the statistical significance of the pair in an expected manner. These include 41 cases where ΔB1 has [-ATR] means statistically significantly higher than [+ATR] indicating wider bandwidths and Normalized A1-A2 has [+ATR] means statistically significantly higher than [-ATR] indicating steeper spectral slopes, 5 cases where the inverse is true, and 35 cases where mean differences in [ATR] pairs are not statistically significant. All five cases where the ΔB1 and Normalized A1-A2 means are contra expectation involve high vowel pairs. The three cases where the ΔB1 means are not statistically significant but Normalized A1-A2 has higher means for [-ATR] vowels than for [+ATR] vowel involve high vowels or cross-height vowels. The three cases where the significance of ΔB1 means is in the expected direction but Normalized A1-A2 means are contra expectation involve low and cross-height vowels. Note that there are no incidences where the significance of ΔB1 means is contra expectation but Normalized A1-A2 means are in the expected direction. The remaining 50 cases involve pairs where ΔB1 means are statistically significantly different but Normalized A1-A2 means are not, or vice versa. Of these 50 cases, ΔB1 has statistically significantly different means in the expected direction 36 times in comparison to 14 times for Normalized A1-A2. Additionally, among mid-vowel pairs, ΔB1 has statistically significantly different means 15 times where Normalized A1-A2 mean differences are not statistically significant, but there are no cases to the contrary. Also, of the 42 possible mid-vowel pairs in this subset, ΔB1 and Normalized A1-A2 agree 43% of the time (18/42). Overall, ΔB1 appears to be a more robust of a measure than Normalized A1-A2 for the data of the languages with nine or ten surface vowels.

The results for the languages with seven surface vowels only involve mid-vowel pairs. There are a total of 60 mid-vowel pairs which were analyzed to determine the statistical significance of ΔB1 and Normalized A1-A2 mean differences.[53] As in the case of the mid-vowels for the languages with nine or ten surface vowels, ΔB1 and Normalized A1-A2 results agree in 43% of these cases (26/60): 11 cases where mean differences are not statistically significant for either measure and 15 cases where their significance is in the expected direction. There are no cases where ΔB1 results indicate a [+ATR] vowel with a statistically significantly different ΔB1 mean, but that there are seven cases where Normalized A1-A2 mean differences are significant but contra expectation. Moreover, there is only one case where Normalized A1-A2 has expected significantly different means but where the ΔB1 mean differences are not significant. Thus, ΔB1 also appears to be a more robust measure than Normalized A1-A2 for the mid vowels of the languages with seven surface vowels, outperforming Normalized A1-A2 in these 27 cases.

The comparison of ΔB1 and Normalized A1-A2 raises several questions. One is why, considering that ΔB1 and Normalized A1-A2 are related measures, Normalized A1-A2 should indicate that certain [-ATR] vowels should have a steeper spectral slope

[53] Note that the Moba speaker is included but that one Londo speaker (1M-CE) is excluded in this subset of the languages.

while ΔB1 suggests that they have wider bandwidths. Another is why the results of ΔB1 and Normalized A1-A2 agree only 43% of the time for mid vowels whether among the nine or ten surface vowel subset or among the seven surface vowel subset.

In order to address these questions, consider first Table 5.16 which summarizes the results of ΔB1 in another fashion. Recognizing that there is an overall tendency across the languages for [-ATR] vowels to have ΔB1 means at or above predicted B1 values and for [+ATR] mid vowels to have ΔB1 means at or below predicted values, but for [+ATR] high vowels to have means either below *or* above predicted values, Table 16 reports the absolute distance (in Hz) between those pairs (whether [ATR] or cross-height) which have statistically significantly different ΔB1 means. As we are primarily interested in those pairs which conform to expectation, those pairs where [+ATR] vowels having statistically significantly greater ΔB1 means than [-ATR] vowels are blocked out with diagonal slashes.

Of the three [ATR] heights possible (high, mid or low), high vowels have the lowest percentage of cases with statistically significantly different ΔB1 means: 40.5% (17/42) of the cases [-ATR] ΔB1 means are significantly greater than [+ATR] ΔB1 means. For another 40.5% of the cases, the [ATR] pairs do not have ΔB1 mean differences which are statistically significant. The rest of the cases (8/42 or 19%) have [+ATR] vowels with significantly greater ΔB1 means than their [-ATR] counterparts. An analogous analysis of low vowels yields more robust results: of the 19 possible pairs, 64% (9/14) have [-ATR] vowels with statistically significantly greater ΔB1 means than their [+ATR] counterparts. Mid vowels present the best results with 83%

(87/104) of the cases having [-ATR] vowels with significantly greater ΔB1 means than their [+ATR] counterparts. Of these 87 cases, there is a near equal spread of front and back vowel pairs (43 vs. 44).

Certain cells in the table are highlighted in yellow if the absolute distance is chosen to be 50 Hz or greater. This choice was made for two reasons. The first reason is considered here while the second reason will be discussed in §5.3.2.

In considering whether ΔB1 is actually more robust a measure than Normalized A1-A2, it is helpful to know whether there is any relationship between the absolute distance of ΔB1 in mid-vowel pairs, since there are no cases where Normalized A1-A2 gives an expected results but ΔB1 does not have statistically significantly different means. When the Ikposo data are compared against the results of A1-A2 no apparent pattern surfaces. For example, speakers 3 and 4 have the highest absolute ΔB1 distances for the mid vowels while speaker 2 has relatively low absolute ΔB1 distances. In the case of speaker 3, the Normalized A1-A2 mean differences are not statistically significant, but they are for both speakers 2 and 3. A similar observation may be made for Ifè. Speaker 5 has the largest absolute distance in ΔB1. Normalized A1-A2 means are statistically significantly different for the front pair but not for the back pair. Speaker 2, on the other hand, has some of the lowest absolute distance in ΔB1. Normalized A1-A2 means are statistically significantly different in both cases. Again, no apparent pattern surfaces and thus no direct relationship absolute distance in ΔB1 and whether Normalized A1-A2 means will be statistically significantly different can be drawn.

Table 5.16 Summary Chart of the Absolute Difference (in Hz) of ΔB1 for [ATR] Harmony and Cross-height Harmony Pairs

Shaded cells indicate no significant difference in ΔB1 means. Cells with diagonal slashes indicate cells whose ΔB1 means are contra expectation. Blank cells indicate non-existing pairs. The numerical value is the absolute difference (in Hz) between ΔB1 pairs. Parentheses indicate results from one-way ANOVA which targeted mid-vowel pairs only. Yellow highlights values of 50 Hz or more.

Language	Speaker	i-ɪ	ɪ-e	e-ɛ	ə-ɑ	ɔ-o	o-ʊ	ʊ-u
Ikposo	1			48	66	46	65	
	2			20	45	42	37	
	3	27		64		100		
	4	44	48	80	37	78	24	
	5	137	111	47		39	44	72
Kinande	1			34		25		
	2		31	105	60	96		
	3			35	69	52		40
	4			37	41	100	57	71
Ekiti	1					79		26
	2	47		38		75		
	3	63	38			52	34	11
Dibole	1			(17)		29		
	2			46		(22)		
	3							
	4			34				
	5			53		46		
Mbonge	1			58		72		
	2			52				
	3			28		39		
	4			45		48		
	5			29		45		
Ifè	1			(20)		36		
	2			29		31		
	3					25		
	4			53		57		
	5			98		84		

Language	Speaker	i-ɪ	ɪ-e	e-ɛ	ə-ɑ	ɔ-o	o-ʊ	ʊ-u
LuBwisi	1			25	60	43	23	
	2	44		33	42			32
	3	34	18	25				21
	4	18		60	83	98		48
	5		49	48		59		
Foodo	1					45	60	
	2		35			32		
	3		57	48			52	
	4	79	107	85		93	33	
Moba	1					32		
Mbosi	1			52				
	2			59		32		
	3			67		55		
	4			80		73		
	5			50		33		
Londo	1			35		54		
	2			23		39		
	3					33		
	4			33		54		
	5			69		45		
Tuwuli	1			30				
	2			39		50		
	3					29		
	4			(21)		40		
	5			37		50		

It is more likely that the lack of statistical significance for Normalized A1-A2 means as well as for those cases where the results of Normalized A1-A2 contradict those of ΔB1 stem from the difficulty of determining observed A1 and A2 when the value of F1 and/or F2 does not align closely with the strongest harmonic associated with F1 or F2. That is, there are numerous cases where F1 or F2 falls somewhere between two harmonics and the researcher must choose between the two harmonics. Sometimes the value of the formant is closer (in Hz) to a weaker harmonic. Sometimes the formant lies in the trough between two harmonics. The researcher has one of two choices in such circumstances: either (1) throw out those tokens where formants do not align closely with a strong harmonic or (2) be as consistent as possible in choosing one harmonic over another in ambiguous cases. I opted for the latter. It is not possible to know which method would give better results unless the data were reanalyzed with ambiguous cases eliminated. In contrast, measuring F1 bandwidth, while not without certain challenges, is nonetheless easier to accomplish with greater accuracy. To the degree that comparing observed B1 with predicted B1 values based on Fant's equation is a reasonable means of comparing the differences of B1 means for vowels which differ in F1 means, then ΔB1 appears to give more robust results that the highly derived Normalized A1-A2 results. (We will return again to Table 5.16 in the discussion of the evidence available in this study for determining the acoustic status of any given degree 2 vowel.)

Table 5.17: Summary of T-Tests of Center of Gravity and F1 Means for [-round] vowels

Numbers = number of speakers at that hertz range whose center of gravity means are significantly different than F1 means. Shaded cells indicate that there are no results for that hertz range. Yellow highlighting indicates the same speaker(s).

Language	[ATR] Value	Non-Significant	x ≤ 0	1-49	50-99	100-199	200-300+
Foodo	[-]					2	2
	[+]					3	1
Ikposo	[-]	1	2		2		
	[+]		3			2	
Kinande	[-]		2	1			1
	[+]	2				1	1
LuBwisi	[-]		1			3	1
	[+]		1			2	2
Ekiti	[-]	1	2				
	[+]	1	1		1		
Ifè	[-]	1	1	1		2	
	[+]			1	2	2	
Dibole	[-]	1		1	2	1	
	[+]			3	1	1	
Mbosi	[-]	1	2			1	1
	[+]		3	1		1	
Mbonge	[-]		4		1		
	[+]		4			1	
Londo	[-]	1	3				1
	[+]	2	1	1		1	
Tuwuli	[-]	1	1	1		2	
	[+]		1	1	1		2
Total	[-]	7	18	4	5	11	6
	[+]	5	14	7	5	14	6

We now turn our attention to the evaluation of center of gravity as seen through the lens of its comparison to F1 means. Table 5.17 summarizes the results for the unrounded vowels for all the speakers of the eleven study languages.[54] [55] The gray

[54] Note that the Mọba speaker's center of gravity data has been excluded from this discussion.
[55] Only unrounded vowels are considered in this summary because of the tendency for rounded vowels, regardless of [ATR] value, to have center of gravities below F1.

shading in the table, where there are no speakers who have results in those particular Hertz ranges, helps to set off those ranges where results converge. Yellow shading stresses that the speakers in those cells are the same. Thus, when the two languages with nine contrastive vowels are compared, the relatively high center of gravity to F1 differences in Foodo can be seen in contrast with those of Ikposo. In Ikposo, center of gravity means tend to be below F1 means. Note again that two Ikposo speakers (highlighted in yellow) have [+ATR] unrounded vowels with greater displacement from F1 than their [-ATR] unrounded vowels.

The results for the three seven-vowel languages with nine or ten surface vowels line up with the two nine-vowel languages in the following manner: apart from the one speaker whose center of gravity to F1 relationship is akin to that of Foodo speakers, the rest of the Kinande speakers pattern with Ikposo, even to having a speaker who has [+ATR] unrounded vowels with greater displacement from F1 than [-ATR] unrounded vowels. LuBwisi, on the other hand, patterns with Foodo, with the exception of the one speaker whose results mirror those of Ikposo. Ekiti also patterns like Ikposo.

The results for those languages with seven surface vowels fall into three main patterns. Firstly, the results for most speakers of Mbonge, Londo and Mbosi fall in the range below F1 means or are not significant. Additionally, Londo and Mbosi each have one speaker whose results are in the same range as Foodo speakers. Mbonge has one speaker whose ranges mirror those of the two Ikposo speakers with [+ATR] unrounded vowels having higher center of gravity to F1 mean ranges than [-ATR] unrounded vowels. Secondly, Dibole stands apart from the other languages with most of the results falling in the mid range of 1-199 Hz. Lastly, the results for Ifè and Tuwuli are scattered across the Hertz entire range.

Overall, the results in Table 5.17 indicate that the relationship of center of gravity to F1 for most speakers falls on the extreme ends of the ranges recorded in this study. Nearly half (25) of the speakers have [-ATR] unrounded vowels with center of gravity means either below or not significantly different from F1 means. Nineteen speakers have [+ATR] unrounded vowels which fall on this end of the spectrum. On the other end of the spectrum, 17 speakers have [-ATR] unrounded vowels and 20 speakers have [+ATR] unrounded vowels with center of gravity means falling in the 100-300+ Hz range. Note that eight of the 17 speakers with [-ATR] unrounded vowels in this range and 8 of the 20 speakers with [+ATR] unrounded vowels in this range are speakers of Foodo and LuBwisi – both languages with nine or ten surface vowels and [+ATR] harmony. Note also that with the exception of the two Ikposo speakers with [+ATR] unrounded vowels and one speaker of Kinande with [-ATR] unrounded vowels, the rest of the speakers with results in the mid range 1-99 Hz range are from the 7-vowel languages with [-ATR] harmony.

While the trends noted in Table 5.17 are meaningful to our understanding of center of gravity in vowel systems with [ATR] harmony, it must be stressed that the table does not tell us whether center of gravity means are significantly different for [ATR] pairs or for cross-harmony pairs: the analysis is limited to what center of gravity's relationship is to F1. The presentation of center of gravity in relationship to F1 is deemed important precisely because there are cases where center of gravity means are statistically significantly different for all [ATR] harmony pairs in Foodo, Dibole and Londo. And yet, the relationship of center of gravity to F1 is very different in each of these languages. How does one know if statistical significance translates into linguistic importance? We will return to this question in §5.3.2 when we consider more closely the importance of vocal register differences in distinguishing vowel quality.

5.3 Distinguishing Phonetically Between 4Ht(H) and 4Ht(M) Systems

Casali (2003:326) raises the overriding question which has driven this current work: "Can 4Ht(H) [ɪ ʊ] and 4Ht(M) [e o] systems be reliably distinguished?" Casali asserts that there is indeed a principled distinction between the inventories of these two systems while, as pointed out in Chapter 1, others such as Clements (1991) have called into doubt whether such a distinction actually exists. According to Casali, the question has been complicated by seeming inconsistencies in categorizing certain Bantu languages. Hyman (1999) illustrates a few of these instances, some of which were pointed out in Chapter 1, namely the Kuperus 1985 analysis of Londo where the degree 2 vowels are reported to *sound* like [e o] but function like [ɪ ʊ]. Such an analysis would classify Londo as a 4Ht(H) language. However, D. Friesen (2002) states that all Oroko dialects, of which Londo is one, have a vowel system with [e o] in their inventory, thus classifying them all as 4Ht(M) languages. Another example of an alternatively transcribed language mentioned earlier from Hyman 1999 and quoted in Casali 2003 is that of Enya (D.14), which has been analyzed as /ị i e a o u ụ/ ([i ɪ ɛ ɑ ɔ ʊ u]) by Koloni

(1971) but as /i e ɛ ɑ ɔ o u/ by Spa (1973). In addition, Hyman also cites Bantu C languages such as Doko (C.31) and Kela (C.75), which illustrate the second degree vowels (transcribed as [e o]) that are claimed to sound close phonetically to high vowels [i u].

Before addressing what phonetic evidence might clearly identify the quality of the height two vowels of any given seven-vowel system with [ATR] harmony, let us consider a short review of the correlation of [ATR] value and a language's underlying vowel system. Our most comprehensive understanding of this relationship comes from Casali 2003, which surveys over 100 languages with one of the three vowel inventories with contrastive [ATR] mentioned in this current study (see Chapter 1). In this survey, Casali challenges what he refers to as the System Independence Hypothesis, namely that the value or values of [ATR] that could be active in a language are not dependent on the language's underlying vowel inventory. Rather, Casali presents evidence from his database for System-Dependent [ATR] Dominance by showing that the value [+ATR] overwhelmingly functions as the dominant value in languages with an [ATR] contrast among high vowels ([i u] and [ɪ ʊ]). On the other hand, [-ATR] dominates in languages in which [ATR] is contrastive only for non-high vowels (in particular, [e o] and [ɛ ɔ]). Stated another way, [+ATR] dominance in seven-vowel languages with the 4Ht(M) inventory are virtually unknown. Casali cites only one: Legbo, a Cross River language of Nigeria. The only other known language with the 4Ht(M) inventory that has been claimed to have [+ATR] dominance is Tuwuli. Harley's (2005) arguments for such an analysis as well as the arguments in favor of a [-ATR] dominance analysis are found in §2.1.3. [-ATR] dominance in 4Ht(H) languages are equally as rare. Casali cites only one example: Kimatuumbi (Bantu P.10).

Knowing beforehand that [-ATR] dominance in 4Ht(H) languages is extremely rare and that [+ATR] dominance in 4Ht(M) languages is equally as rare is important top-down information to have playing in the background as we consider what bottom-up acoustic facts informs our understanding of the make-up of the height 2 and height 3 vowels, firstly in unambiguously analyzed systems such as Foodo, Ikposo, Dibole or Mbosi and secondly in languages like Londo and Tuwuli whose underlying vowels have alternative analyses or Tuwuli, where the dominant [ATR] value is in dispute.

5.3.1 Evidence from F1

The discussion of the phonetic evidence for determining the quality of any given degree 2 vowel of necessity starts with F1, the acoustic correlate that is unambiguously associated with [ATR] in all acoustic studies of languages with [ATR] harmony to date. We tackle first the question of the differences between degree 1 and 2 vowels in 7-vowel languages. For example, the importance of F1 in distinguishing degree 1 and 2 vowels in the four-height seven-vowel systems with high-vowel harmony (4Ht(H)) is seen in the degree to which F1 mean differences for /i u/ are statistically significant from /ɪ ʊ/. In Casali 2003 several seven-vowel languages with high vowel harmony are cited for which /ɪ ʊ/ are said to be difficult to distinguish perceptually from /i u/, Talinga-Bwisi (i.e. LuBwisi), as cited from Paluku 1998, being one of these languages.

On the other hand, Casali goes on to say that he is aware of very few "4Ht(M) languages for which serious auditory confusion between any of the adjacent vowel heights has been reported, despite the fact that such vowel systems are extremely common and widespread" (Casali 2003:343).

The relevance of these statements can be considered via the aid of Table 5.18 which summarizes the pooled F1 means for degree 1 and 2 vowels the eleven study languages, as well as the degree 2 and 3 vowels for those languages with nine or ten surface vowels. In Foodo, LuBwisi and Ekiti, the differential of the F1 means for their degree 1 and 2 vowels, as well as degree 1 and 3 vowels do not differ substantially. The differentials for all four vowel pairs are well over 100 Hz. Based on the differential of F1 mean differences alone it seems unlikely that the high vowels of LuBwisi would be any more difficult to distinguish perceptually than those of Foodo. On the other hand, the degree 1 and 2 vowels of Ikposo have much smaller differentials. My personal experience with Ikposo suggests that it can be difficult to perceive the difference between front high vowels in isolation based on F1 alone.[56] Perhaps 65 Hz is too small a mean differential for the ear accustomed to larger F1 mean differences between degree 1 and 2 vowels. (In contrast, I do not have difficulty perceiving the difference between back high vowels with a mean differential of 97 Hz. As reported in Anderson 1999, it was the degree 2 and 3 vowels I initially confused until I began listening for the vocal register differences that distinguish these vowels.)

[56] "In isolation" would include cases where the command form of monosyllabic verbs. I also cannot necessarily tell the difference between *ítí* 'sorcery' and *ɪ́tɪ́* 'temps' with any accuracy unless I hear the pairs side by side.

Table 5.18: Pooled F1 Means for Degree 1 and 2 Vowels for all Eleven Languages

Numbers below dotted lines indicate the F1 differential.

	Pooled F1 means in Hz			
	i-ɪ	i-e	u-ʊ	u-o
Foodo	328-477 149	328-493 165	360-493 133	360-523 163
LuBwisi	300-434 134	300-436 136	330-441 111	330-466 133
Kinande	299-403 104	299-381 82	326-397 71	326-407 81
Ikposo	246-311 65	246-398 152	275-372 97	275-379 104
Ekiti	242-365 123	242-360 118	271-371 100	271-383 112
Ifè		300-426 126		316-429 113
Dibole		295-382 87		334-400 66
Mbosi		257-416 119		318-431 113
Mbonge		300-360 60		304-382 78
Londo		284-382 98		324-417 93
Tuwuli		302-375 73		329-409 80

When the languages with seven surface vowels are considered we see that with the exception of Ifè and Mbosi, the differential of F1 means for the degree 1 and degree 2 vowels for Dibole, Mbonge, Londo and Tuwuli never attains 100 Hz. F1 as a reliable means for determining the quality of the degree 2 vowels for these languages is further complicated by examples like Mbonge where the front vowels have a lower F1 mean differential than Ikposo height 1 and 2 vowels but where back vowels have an F1 mean differential that falls in between Kinande degrees 1 and 2 and 2 and 3 vowels.[57] Therefore, F1 mean differentials for degree 1 and 2 vowels do not necessarily help much in answering our question.

5.3.2 Evidence from Bandwidth

We turn next to the secondary acoustic measures, first to bandwidth and then center of gravity. Recall from §5.2.12 that certain cells of Table 5.16 with an absolute ΔB1 distance of 50 Hz or above were highlighted in yellow for two reasons. The first reason for doing so was to compare values below and above the 50 Hz mark with Normalized A1-A2 patterns. The second reason is to compare the percentage of mid vowels, in particular, for 7- and 9-vowel languages with absolute ΔB1 distances of 50 Hz or higher. Considering first the languages with nine or ten surface vowels, of the 35 mid-vowel pairs which have statistically significantly different ΔB1 means, 16 or 46% of these have absolute ΔB1 distances of 50 Hz or higher. There are 51 mid-vowel pairs with statistically significantly different ΔB1 means among the languages with seven surface vowels. Twenty or 39% of these pairs have absolute ΔB1 distances of 50 Hz or higher. The percentage of mid-vowels pairs with robust ΔB1 means is only 7% higher for the languages with nine or ten surface vowels. We can tentatively say that mid-vowel pairs for the languages with seven surface vowels are patterning in a similar way as the mid-vowel pairs are for the languages with nine or ten surface vowels.

[57] Note that Dibole is another example of a language with especially an especially low F1 mean differential for degree 1 and 2 vowels. In personal correspondence with Myles Leitch who has done a bit of study on Dibole, I mentioned the fact that I had trouble hearing the difference between degree 1 and 2 vowels in the speech of some speakers. While Myles acknowledges that there is a tendency for some researchers to hear these vowels as the same, he has wondered about that. He himself never had trouble distinguishing or transcribing these vowels as they form a robust contrast in the system of oppositions.

Another way of comparing the degree 2 vowels of the languages with seven surface vowels with the degree 2 and 3 vowels of the languages with nine or ten surface vowels is by observing how these vowels pattern in the homogeneous subsets of the ANOVA run for ΔB1. Table 5.19 presents the results of the pooled data for each language. While there are certainly differences between speakers in terms of numbers of homogeneous subsets and members of those subsets, the pooled data best reveal the trends of each language as well as the overall trends cross-linguistically for these datasets.

Table 5.19: Homogeneous Subsets for Pooled ΔB1 for all Eleven Study Languages

Periods set off homogeneous subsets. Horizontal bars indicate a clear demarcation between [+ATR] and [-ATR] vowels.

<table>
<tr><th>Language</th><th>Homogeneous Subsets</th></tr>
<tr><td>Foodo</td><td>3: eo.|ɛʊɔɪɑi.u</td></tr>
<tr><td>Ikposo</td><td>7: ieo.ou.uɪ.|ɪʊ.ʊɛ.ɔə.ɑ</td></tr>
<tr><td>Kinande</td><td>4: euoɪ.ɪiʊ.|ɛɔə.ɑ</td></tr>
<tr><td>LuBwisi</td><td>6: ieu.uoɪʊ.|ɪʊə.ʊəɛ.ɔ.ɑ</td></tr>
<tr><td>Ekiti</td><td>5: eo.|ɛɔɪ.ɔɪʊ.ʊɑi.u</td></tr>
<tr><td>Ifè</td><td>4: eio.iou.|ɛɔ.ɑ</td></tr>
<tr><td>Dibole</td><td>5: e.io.|oɛ.ɔu.uɑ</td></tr>
<tr><td>Mbosi</td><td>5: eo.iu.|ɔ.ɛ.ɑ</td></tr>
<tr><td>Mbonge</td><td>6: e.io.ou.|ɛ.ɔ.ɑ</td></tr>
<tr><td>Londo</td><td>5: eio.ou.|ɛ.ɔ.ɑ</td></tr>
<tr><td>Tuwuli</td><td>3: ie.ouɛ.|ɔɑ</td></tr>
</table>

The first trend, which supports the results discussed for Table 5.16, is that there is a clear demarcation between [+ATR] and [-ATR] mid vowels for all eleven languages. The vowels [e] and [o] tend to not occur in the same homogeneous subset with [-ATR] mid vowels and they never occur with the [-ATR] low vowel [ɑ]. The vowel [e] always occurs in the first homogeneous subset, which represents the lowest ΔB1 means. In seven cases, both [o] and [e] occur in the first subset. In Dibole and Tuwuli, the two cases where [o] occurs in the same subset as a [-ATR] mid vowel, it is always [ɛ] and never [ɔ]. Again, we know from previous discussion that Dibole and Tuwuli have the least number of [ATR] harmony pairs with statistically significantly different ΔB1 means. These differences are leveled in the pooled data.

The second trend concerns the [-ATR] high vowels for the languages with nine or ten surface vowels. The pattern for the pooled data of Foodo, Ikposo and Ekiti is for [-ATR] high vowels to pattern with [-ATR] mid vowels. Again, there is considerable variety in the patterns of individual speakers. There is much less of a tendency in LuBwisi and Kinande for [-ATR] high vowels to fall in the same subset as [-ATR] mid vowels and for more of a tendency for them to pattern rather with [+ATR] high vowels.

The final trend concerns the relationship between [i u] and [e o]. In five cases [i] and [e] fall into the same subset and in seven cases [u] and [o] fall into the same subset. In all other cases, [i] and [u] fall into a higher subset than [e] and [o] respectively. This pattern holds for all eleven languages. On the other hand, in the languages with nine or ten surface vowels, [ɪ]and [ʊ] fall either into higher subsets than [e] and [o] or in the same subset.

Based on these three trends: the clear demarcation of [+ATR] and [-ATR] mid vowels across all eleven languages, the tendency for [-ATR] high vowels to pattern either with other [-ATR] vowels or with [+ATR] high vowels in languages with nine or ten surface vowels and for high vowels to either fall into the same or higher subsets than [e] or [o], we can now assert with a higher level of confidence that the degree 2 vowels of the languages with seven surface vowels, namely Ifè, Dibole, Mbosi, Mbonge, Londo and Tuwuli are patterning like the [+ATR] mid vowels of Foodo, Ikposo, Kinande and LuBwisi. Based on how similarly [ATR] mid vowels behave in terms of F1 bandwidth, it seems fairly clear that the same cover feature, namely [ATR], is adequate to describe their acoustic behavior. It is not so easy to leap to an assertion concerning how these vowels are produced articulatorily. It would be premature to claim that there is categorically either a constriction or expansion of the pharyngeal cavity associated with the production of one or more of the mid-vowel pairs in the six languages listed above. If one assumes that Fant's formula for modeling vocal tract losses is a reliable measure of [ATR] differences, then there is every likelihood that there is an expansion or constriction of the pharyngeal cavity. However, until this method is applied to more data that include languages with seven surface vowels with the 4Ht(H) system as well as languages with five or seven vowels without any form of harmony (height or [ATR]), we cannot know for sure.

5.3.3 Evidence from Center of Gravity

Appealing to F1 bandwidth certainly does not convey the full story of the acoustic (or articulatory) similarities or differences among the languages, even between those languages with essentially the same underlying vowel system and [ATR] dominance. Take the example of Foodo and Ikposo, both canonical examples of 9-

vowel languages with [+ATR] dominant vowel harmony.[58] As has been stressed throughout this work, the acoustic manifestations of those underlying vowels are systematically different between the two languages. Consider first a comparison of F1 means of [-round] vowels for the pooled data for Ikposo and Foodo (Table 5.20). Since there are known gender differences in the datasets, the mean ranges of F1 are also included for each vowel. The higher number of the range is always a mean of a female speaker, the lower number of the range is in most cases a male speaker.

Table 5.20: Center of Gravity Means in Foodo and Ikposo – Pooled and Ranges

Shaded cells in Foodo column = mean differences that are not significant. Highlighting in Ikposo column = overlapping means of a female and male speaker.

	Foodo	Ikposo
i	328	246
	311-357	221-275
ɪ	477	311
	426-539	261-363
e	493	398
	416-587	317-512
ɛ	671	523
	572-753	417-688
ɑ	894	776
	825-949	717-826

This comparison assumes that combining the data of males and females has a leveling effect on the vocal tract length differences that tend to accompany male and female speakers – males tending to have longer vocal tracts and larger heads, resulting in overall lower F1 formant frequencies. So, barring the unlikelihood of five individuals (male and female) in Ikposo who all have relatively larger vocal tracts than the four

[58] The 10th vowel /ə/ of Ikposo is ignored in this section for the purposes of argumentation.

individuals (also male and female) in Foodo, the picture which emerges is one in which Ikposo has relatively lower F1 mean frequencies for front vowels and [a] in comparison to Foodo. Of particular interest is the fact that Ikposo /i/, /ɪ/ and /e/ all have mean values that are lower than either Foodo /ɪ/ or /e/. The net effect in Ikposo is a crowding of acoustic space in the 260-360 Hz range. Foodo, on the other hand, crowds acoustic space in the 425-525 Hz range. In Ikposo, the result is statistically significantly different F1 means for /i/, /ɪ/ and /e/, with some overlap of the F1 means for male and female speakers in [ATR] harmony and cross-height pairs. In Foodo, on the other hand, the range of F1 means for /i/ and /ɪ/ do not overlap at all, but the range of F1 means for /ɪ/ is completely within the range of the F1 means of /e/.

Though we only have the indirect evidence of the production of these two vowel systems (via the acoustic data), the assumption presented here is that the vowels of Ikposo and Foodo are not articulated in the same manner. From other works that have included articulatory studies, we know that [ATR] differences can be affected in a variety of ways: expanding or constricting the pharyngeal cavity, raising or lowering the larynx, or perhaps a combination of the two. Edmondson and Esling (2006) have also shown that sphinctering of the aryepiglottic folds is involved in the production of [-ATR] vowels in Kabiye and Akan. Lowering the larynx is known to lower F1 frequencies. Raising the larynx, which would shorten the vocal tract, would presumably have the opposite effect. Certainly constricting the aryepiglottic folds at the end of the vocal tract would reduce both the length and the volume of the vocal tract. The hypothesis advanced here is that the production of [+ATR] vowels in Ikposo most likely involves a lowering of the larynx, which produces much lower F1 values for high and mid vowels. On the other hand, the [-ATR] vowels of Foodo most likely involve a raising of the larynx quite possibly resulting from the sphinctering of the aryepiglottic folds.

However, until laryngoscopic observation of the production of Ikposo and Foodo vowels can be made, what can be done is to compare the Foodo vowel acoustics to, for example, Kabiye. In Edmondson, Padayodi, Silva and Esling 2008 the mean F1 values for the [–round] vowels for one female speaker are as follows: [i, 309], [ɪ, 514], [e, 548], [ɛ, 706], [a, 890].[59] Note that all these mean values fit well within the range of Foodo vowels but outside of Ikposo vowels.

Since it is known that the [-ATR] vowels of this Kabiye speaker are produced with aryepiglottic sphinctering (a constriction of valve 3), the results for center of gravity reported in Edmondson et al. 2008 are particularly relevant to our understanding of Foodo and Ikposo acoustics. Recall from §3.3 that Edmondson and Esling (2006b) predict that if there is a constriction at valve 3 that it would most likely have a reflex in the wave profile, with [-ATR] vowels having potentially higher center of gravities than their [+ATR] counterparts. This was found to be widely true in most languages of this current study, but that these results need to be interpreted based on the displacement of

[59] Note that these measures are my own calculations of the data points supplied to me by one of the authors of Edmondson et al. 2008. I take full responsibility for any discrepancies between what I have reported here and the forthcoming paper and urge the reader to consult that work.

center of gravity mean from F1 mean. Therefore, consider that for the same five vowels in Kabiye mentioned above that the center of gravity means are as follows: [i, 390], [ɪ, 668], [e, 554], [ɛ, 776], [a, 996]. My own calculations of the data (used with permission) show that the [–round][-ATR] vowels have center of gravity means 116 Hz above F1 means, while the [–round][+ATR] vowels have center of gravity means only 17 Hz above F1 means. These results, though not as robust as the Foodo results, tend in the same direction: [-ATR] vowels have robustly higher center of gravity means than F1 means. The opposite was true for Ikposo. Three of the speakers had center of gravity means statistically significantly lower than or not significantly different than F1 means. The other two speakers, two males with high center of gravity means for [+ATR] /i/, had results in the opposite direction: [–round][+ATR] vowels had center of gravity means robustly higher than F1 means, but [–round][-ATR] only moderately above F1 means.

Based on these comparisons, and the likelihood that Foodo vowels are articulated more similarly to Kabiye vowels than to Ikposo vowels, we can revisit the role of center of gravity in the comparison of the height two and height three vowels of the 7-vowel languages with ten surface vowels with [ɪ ʊ] and [e o] of the 9-vowel languages. Beginning with Kinande, we discovered that one of the speakers, 4F-Jc, had center of gravity means that pattern like those of Ikposo speakers (with center of gravity means lower than F1 means) while another speaker, 2M-Ks, had center of gravity means that pattern like those of Foodo speakers. Note that one of the major differences between the vowels of these two Kinande speakers is the mean value of center of gravity for their height two vowel /ɪ/. The mean for 4F-Jc is 482 Hz, but 774 Hz for 2M-Ks. The center of gravity means for cross-height vowels [ɪ] and [e] for speaker 2M-Ks are statistically significantly different, but not so for speaker 4F-Jc. Note that for 4F-Jc that these vowels do not have statistically significantly different F1 means, but that they do for 2M-Ks. In the case of the latter speaker, [e] has the lower F1 mean. In listening to tokens of [ɪ] and [e] for speaker 4F-Jc, I can hear no difference either in height or "voice quality." In the case of 2M-Ks, [-ATR] [ɪ] seems "brighter" and "tenser" than [e], which sounds more "dull." In other words, there is acoustically no real difference between the cross-height vowels of speaker 4F-Jc, but there is for speaker 2M-Ks.

The differences detailed in the previous paragraph underscore the inter-speaker variation that exists not just in Kinande but in the rest of the seven-vowel languages and to a certain degree in Ikposo. I propose that these differences emanate from whatever strategy speakers use to maintain contrast between height 1 and height 2 vowels (i.e. /i u/ and /ɪ ʊ/). Is it possible that speaker 4F-Jc lowers her larynx for [+ATR] /i/ while speaker 2M-Ks raises his for [-ATR] /ɪ/? That is, does it matter what strategy is used by a given speaker, so long as the distinction between high vowels is maintained? It is known, for example, in Gick et al. (2006) that one male speaker of Kinande manipulated his pharyngeal space differently for [+ATR] and [-ATR] vowels. An experiment using ultrasound technology showed that tongue-root position varies systematically across vowels with [+ATR] vowels having greater anterior tongue-root position than [-ATR] vowels. Most importantly, they showed that only high vowels are completely distinct. In the case of speaker 2M-Ks, regardless of how he is producing the difference between /i/ and /ɪ/, it results in systematically high center of gravity measures.

Note that similar arguments can be made for LuBwisi, where again the critical distinction to maintain is between high vowels /i u/ and /ɪ ʊ/. Four of the five speakers have center of gravity means for [ɪ] in the 625-820 Hz range, as do Foodo speakers and the Kabiye speaker of Edmondson et al. 2008. For these speakers again, center of gravity measures are systematically high. For four speakers, cross-height vowels have F1 means which are not statistically significantly different. What is to prevent us from concluding that this is evidence of complete height assimilation – namely, that for some of the speakers there are other acoustic correlates which are significantly different. Of the four speakers with high center of gravity means, the two males have significantly higher center of gravity means for their [-ATR] vowel of the pair. This is not so, however, for the two females. For one of the female speakers, the vowels are distinguished by F1: the [+ATR] vowel has a significantly higher F1 mean than the [-ATR] vowel. For the other female speaker, F1 bandwidth values are significantly different: the [-ATR] vowel has a significantly higher F1 bandwidth mean than the [+ATR] vowel. Therefore, even without the support of an articulatory study, the acoustic evidence supports the hypothesis that LuBwisi speakers are manipulating tongue root position in some fashion to distinguish [ATR] pairs. But what about the [ATR] pairs for the seven-vowel languages with seven surface vowels?

5.3.4 Vocal Register Differences: Charting the Direction of Future Research

Up to this point in the discussion, several references have been made to so-called "voice quality" (i.e. vocal register) differences in certain vowels without clearly reiterating their importance. As was pointed out in Chapter 1, many studies of 5Ht languages have reported vocal register differences associated with the two [ATR] sets. Typically, [+ATR] vowels have been given impressionistic labels such as "hollow," "deep," breathy," etc. while [-ATR] vowels have been described as "tight," "choked," "bright". As Casali (2003) points out, these qualitative distinctions are apparently the perceptual cues which allow for otherwise acoustically overlapping vowels to remain perceptually distinguishable. In this study, we have seen evidence of F1 overlap in all of the languages with nine or ten surface vowels and we have also seen one or more secondary acoustic correlates such as bandwidth differences or center of gravity differences which are the likely acoustic reflexes of impressionistic vocal register differences. To what degree are these vocal register distinctions present in the 7-vowel systems of this study?

This is the question that should drive future study of the degree 2 vowels of not only the 7-vowel systems in this work (or languages like them) but of languages not included in this study, 7-vowels with a 4Ht(H) system but no allophonic variation in mid or low vowels as well as 7-vowel systems without [ATR] or height harmony. In the initial conception of this study, it was proposed that perceptual tests accompany the acoustic study. This line of study was abandoned when the magnitude of the acoustic study in and of itself became clear. It was also clear that a carefully designed perceptual study could easily stand on its own as a dissertation.

The rest of this section is a brief example of the potential of testing center of gravity differences perceptual differences. Its purpose is not to suggest how a perceptual study should be undertaken but rather to illustrate that there are in fact perceptual differences associated with even the limited set of data arbitrarily chosen for inclusion in the test.

I designed a small perceptual test in order to ascertain my own impressions of any vocal register differences that may be associated with the height 2 and height 3 vowels of the languages in this study. I chose tokens of [e] and [ɪ] from three languages with 9(10) surface vowels (Foodo, Ikposo, and LuBwisi) and tokens of [e] from two languages with 7 surface vowels (Dibole and Ifè). An attempt was made to include tokens with similar fundamental frequencies and so I tested one token of a vowel from male speakers with an F0 of 160-200 Hz. In addition, I also chose LuBwisi speaker 2M-H whose vowel center of gravities pattern like Ikposo and not like Foodo. To these tokens I included tokens from the Nawdm language, which is part of the larger database from which the languages of this study are drawn. Nawdm is of interest precisely because one of its dialects is classified as having a Ht4(M) inventory and another as having a Ht4(H) inventory. Additionally, I have been told that the differences between the vowel systems are also qualitative in nature. Native speakers of the Ht4(M) dialect are known to mimic in jest the quality they perceive in the speech of speakers of the

Ht4(H) dialect (Jacques Nicole, personal correspondence). Therefore, one token of a degree two vowel of a speaker of Western Nawdm (Baga) and one token of a degree two vowel of a speaker of Eastern Nawdm (Siou) are included for comparative purposes. From the steady state of each vowel, I measured the first three formants, the fundamental frequency and the center of gravity. The results are found in Table 5.21.

Table 5.21: F1, F2, F3, Fundamental Frequency and Center of Gravity Measurements for Perceptual Test Tokens

Language	Word	F1	F2	F3	F0	CoG
Ikposo 2M-Jo	use	325	1968	2652	160	350
LuBwisi 2M-H	ki-tel-i	382	1971	2467	169	439
Dibole 3M-C	ses-a	357	1815	2613	170	410
Ifè 1M-Kv	se	345	1992	2389	167	364
Nawdm-Baga	a-deedan	414	2211	2847	200	431
Foodo 1M-K	o-keeli	382	2211	2490	176	518
Ikposo 2M-Jo	ɪtɪ	327	2013	2818	167	543
LuBwisi 2M-H	kɪ-sɪɪk-a	410	1912	2565	182	457
Foodo 1M-K	ɔ-tɪɪlɪ	425	2086	2945	182	850
Nawdm-Siou	a-dɪɪran	447	1677	2459	169	851

Next I listened randomly to the various vowel tokens irrespective of their quality and grouped them according to a following impressionistic perceptual quality: “hollow/ resonant,” “tight,” “constricted” or “neutral.” These impressions are listed in Table 5.22.

Table 5.22: Results of the Perceptual Quality Test

Language	Vowel	Perceptual Quality	F1	F2	F3	F0	CoG
Ikposo 2M-Jo	e	hollow/resonant	325	1968	2652	160	350
Ifè 1M-Kv	e	hollow/resonant	345	1992	2389	167	364
Ikposo 2M-Jo	ɪ	tight	327	2013	2818	167	543
Foodo 1M-K	e	tight	382	2211	2490	176	518
Foodo 1M-K	ɪ	constricted	425	2086	2945	182	850
Nawdm-Siou	ɪ	constricted	447	1677	2459	169	851
Nawdm-Baga	e	neutral	414	2211	2847	200	431
LuBwisi 2M-H	e	neutral	382	1971	2467	169	439
LuBwisi 2M-H	ɪ	neutral	410	1912	2565	182	457
Dibole 3M-C	e	neutral	357	1815	2613	170	410

Since this was an ad hoc impressionistic study some point of reference for comparison was also needed, therefore I compared the quality of the vowels to my native language, American English, which is known to have tongue root displacement associated with "tense" and "lax" vowels:

- The [ɪ] of the LuBwisi speaker sounds a bit "higher" and more centralized than [e], like English [ɪ].
- The [ɪ] of the Foodo speaker and of Nawdm-Siou speaker also sounds like English [ɪ] but has a much more constricted quality to it.
- The [ɪ] of the Ikposo speaker sounds like a kind of [i] but with a more constricted quality to it.

- The [e] of the Nawdm-Baga speaker sounds like the [ɪ] of the LuBwisi speaker.
- The [e] of Dibole speaker sounds like the [e] of Nawdm-Baga and the [ɪ] of the LuBwisi speaker.
- The [e] of the Ikposo and Ifè speakers sound the same in height and vocal register.
- The [e] of the Foodo speaker has the same degree of "tension" as Ikposo [ɪ], but the Ikposo sound is perceptually "higher" (it sounds like a kind of "i" while the Foodo sound sounds like a kind of "e").

After assembling these vowel tokens according to my impressions, I noted that all the vowels grouped together by impressionistic criteria fall into the same frequency range for center of gravity. That is, vowels that perceptually sound the most constricted have center of gravity values higher than 800 Hz. Those that sound somewhat constricted ("tight") fall into the 500 Hz range. Those that sound the least constricted, more resonant or hollow fall into the 300 Hz range. All the vowels that struck me as being "neutral," i.e. without any particular vocal register difference associated with them, fall into the 400 Hz range.

These conclusions, though based on a limited set of impressionistic judgments as correlated with quantifiable acoustic measurements, point in the direction that there is a perceptual continuum that is "resonant" sounding at one end and "constricted" at the other end. In the middle of these extremes is a third category, which I term "tight." Of particular interest is the fact that this category applied to the [+ATR] token from the

Foodo speaker, but to the [-ATR] token from the Ikposo speaker. What is important about this middle ground is that it contrasts with either of the two extremes in a binary system. Outside of the system altogether is the "neutral" setting that I heard for vowels from the Dibole and LuBwisi speaker. In other words, I perceive two marked settings for each of the 9-vowel systems with CHVH in this study. They are not, however, the same two settings, but rather involve a setting that is associated with a [+ATR] mid vowel in one case but a [-ATR] setting in the other.

For some of the 7-vowel languages, however, the height two or three vowels sound "neutral" and thus potentially unmarked. Of particular importance here is that the [e] of Dibole and the [ɪ] of LuBwisi sounded the same to me. Is this then evidence supporting a height analysis à la Clements 1991 or Parkinson 1996? Possibly yes. However, I would undoubtedly have found very different results for both Dibole and LuBwisi had I chosen, for example, Dibole speaker 3F-S and LuBwisi speaker 3M-W whose [e] vowels have center of gravity frequencies in the 500s, results perhaps more like those of the Foodo speaker, suggesting a constriction in the pharyngeal cavity. Such differences suggest that vocal register differences can, but do not necessarily, accompany 7-vowel languages, whether there are seven or ten surface vowels.

5.5 Concluding Remarks

The results presented in the previous section are not at all outside the realm of possibility predicted by Kingston et al. in their 1997 study of vocal register perceptions of tongue root position. Kingston and his associates discovered in their study how a more lax vocal register may integrate with a more advanced tongue root position into a single perceptual category they refer to as “spectral flatness.” In their perceptual study, they discovered that listeners are more sensitive to flatness at the extremes of the vocal register continuum but not in the middle region. From this study, Fulop et al. (1998) developed Normalized A1-A2 to measure spectral flatness in Degema. Guion et al. (2004) applied this technique also to Maa. However, as discussed in §5.2.12, Normalized A1-A2 is a highly derivative measure, and thus appears to have been less useful in this study for measuring spectral flatness than ΔB1 or the direct observation of center of gravity. Kingston et al. have in fact suggested that center of gravity is an analogous measure of flatness. I, for one, appear to be sensitive enough to differences in center of gravity to group vowels in the same frequency range for center of gravity together. Presumably, Nawdm speakers, whose height two vowels differ perceptually in my estimation between “neutral” and “constricted,” must also be sensitive to these differences. If not, we are harder pressed to explain why speakers of Nawdm speakers playfully mimic the vocal register differences of Nawdm speakers of other dialects.

With the assumptions being made about the perceptual distinctiveness of center of gravity differences running in the background, consider the comparison of the center of gravity means for height 2 and 3 vowels for the 11 languages of this study (Table 5.23). This table predicts that the vowels of the languages with seven surface vowels will have, on the average, a resonant to neutral quality to them. There will be speakers whose degree 2 vowels will have a somewhat constricted quality to them. It is interesting to note that in this study, the highest mean in the range for the seven surface vowel languages comes invariably from a female speaker. More study will need to be conducted to learn whether this was incidental to this study or a tendency across 7-vowel languages with [ATR] harmony. This was not the case for the languages with 9(10) surface vowels. Males tend to have the higher center of gravity means for /ɪ/. There is no particular trend for /e/.

Table 5.23: Pooled Means and Mean Ranges of Center of Gravity for all Eleven Study Languages

<table>
<tr><th></th><th>Height 2 - /ɪ/</th><th>Height 3 - /e/</th></tr>
<tr><td>Foodo</td><td>782
636-956</td><td>602
467-672</td></tr>
<tr><td>Ikposo</td><td>368
244-444</td><td>412
282-523</td></tr>
<tr><td>Kinande</td><td>528
375-774</td><td>460
392-507</td></tr>
<tr><td>LuBwisi</td><td>667
418-821</td><td>574
383-673</td></tr>
<tr><td>Ekiti</td><td>401
310-579</td><td>357
300-462</td></tr>
<tr><td>Ifè</td><td colspan="2">483
411-589</td></tr>
<tr><td>Dibole</td><td colspan="2">440
328-550</td></tr>
<tr><td>Mbosi</td><td colspan="2">437
336-568</td></tr>
<tr><td>Mbonge</td><td colspan="2">382
290-608</td></tr>
<tr><td>Londo</td><td colspan="2">401
299-619</td></tr>
<tr><td>Tuwuli</td><td colspan="2">549
397-970</td></tr>
</table>

Can we conclude from these results that if given any degree 2 vowel with a “neutral” quality associated with it that it is a height three, i.e. /e/, vowel rather than a height two or /ɪ/ vowel? Not necessarily. That is, not based on center of gravity results alone. The ΔB1 results may end up being the measure that is most reliably invoked to decide the issue. The Ikposo results caution us that both /ɪ/ and /e/ can have relatively neutral settings. In addition, there was at least one speaker in both LuBwisi and Kinande whose /ɪ/ and /e/ vowels had relatively neutral settings. What we can potentially conclude, though, is that if a degree 2 vowel has a center of gravity value in the 700 Hz range, there is a strong likelihood that it is produced with a fair amount of constriction somewhere in the vocal tract. There are no occurrences in the data presented in this study for a vowel that has been analyzed as /e/ ever having center of gravity values in the 700 Hz range, except for one Tuwuli speaker. And in the case of the Tuwuli speaker, all her vowels had a very high center of gravity mean, suggesting that the higher levels resulted from an overall more constricted articulatory setting.

The fact that some speakers appear to have more constricted and others to have more lax articulatory settings is an important one for this study and for the study of the degree 2 vowels in 7-vowel languages in general. Ultimately, the degree 2 vowels have to be evaluated not just acoustically, but in comparison to the rest of the vowels in the system of which they are a part. In a language like Foodo, height 2 and 3 vowels overlap acoustically for F1, but other perceptual cues, such as bandwidth differences or center of gravity differences, aid in maintaining their perceptual distinctiveness. But then, so does the phonology. For the most part, the [-ATR] high vowels do not occur in isolation, but as part of a verb phrase with harmonizing clitics or a noun with harmonizing class markers. Thus the system itself mitigates against confusion potentially arising from either inter-speaker variation or simply missing the target.

This study has presented a description, analysis, and interpretation of the various acoustic correlates associated with [ATR] in eleven Niger-Congo languages known to have varying degrees of [ATR] harmony. Five languages with nine (or ten) surface vowels were presented, two of which have underlyingly nine or ten vowels and three of which have seven underlying vowels. Six languages have seven underlying and surface vowels. One of the major results of the study is that center of gravity measurements very likely contribute to the perceptual flatness of a vowel, a secondary feature that can be exploited in languages phonemically.

This study also moves the discussion of whether 7-vowel languages with mid-vowel harmony are best analyzed with the features [ATR]/[RTR] or with [closed]/[open] to another level. The fact that degree 2 vowels in the 7-vowel languages with seven surface vowels in this study are neither especially constricted or resonant sounding does not help to resolve this question. However, the results of comparing observed F1 bandwidth values to the Fant formula for modeling vocal tract losses does add compelling argument to interpreting the differences between degree 2 and 3 vowels as one based in the acoustic differences associated with [ATR]. Ultimately, an articulatory study using laryngoscopy would certainly shed light on any articulatory settings at the larynx that are being manipulated in the production of vowels deemed to be specified for [ATR]. Even a definitive “no” from such a study would still leave open the door to the possibility that the features [ATR]/[RTR] may not have any perceptual correlates other than F1 mean differences distinguishing [ATR] harmony pairs.

APPENDIX A

WORD LISTS

Londo (Bantu A.10) Compiled from Kuperus 1985

i	[dì-sìsà]	‘to frighten
	[dì-títà]	‘to be small’
e	[dì-sèkà]	‘to shape (carve)’
	[dì-tèkà]	‘to mark’
ɛ	[dì-sɛ̀bɛ̀]	‘to cradle’
	[dì-tɛ̀kɛ̀]	‘to pound’
ɑ	[dì-sɑ́kɑ̀]	‘to dance’
	[dì-sɑ̀kɑ̀]	‘to want’
ɔ	[dì-sɔ́sɔ̀]	‘to suck’
	[dì-tɔ̀kɔ̀]	‘to talk’
o	[dì-kófɑ̀]	‘to hold’
	[dì-sòswɑ̀]	‘to wash’
u	[dì-túkɑ̀]	‘to suffer’
	[dì-tútɑ̀]	‘to peg out skin, make drum’

Mbonge (Bantu A.10) Compiled from *Oroko Lexical Database* version March 2003, D. Friesen

i	[dì-sìsà]	'to threaten'
	[dì-tìlà]	'to write'
e	[dì-kèkà]	'to try'
	[dì-tétá]	'to insist/urge'
e/ɛ	[dì-tɛ́lɛ́]/[dì-télɛ́]	'to open a door, container, pot'
ɛ	[dì-sɛ̀bɛ̀]	'to cradle'
ɑ	[dì-sɑ́kɑ́]	'to dance'
	[dì-sɑ̀kɑ̀]	'to want'
ɔ	[dì-sɔ́sɔ́]	'to suck'
	[dì-sɔ̀sɔ̀]	'to talk'
o	[dì-sókɑ́]	'to set a hook, snatch'
	[dì-sòsɑ̀]	'to wash'
u	[dì-sùkɑ̀]	'to pull'
	[dì-tútɑ́]	'to cover'

Dibole (Bantu C.20) Compiled from *Dictionnaire Dibole – Français* version 2004, in consultation with Myles Leitch and Dibole consultants.

i	[sídzá]	'finir, achever imp.'
	[sìlá]	'aiguiser imp.'
e	[sésá]	'admirer imp.'
	[e-hésé]	'os, arrête de poisson'
ɛ	[sɛ́lɛ́]	's'éloigner imp.'
	[tɛ̀hɛ́]	'refuser de faire qqch. imp.'
ɑ	[sálá]	'travailler'
	[ɑ-sàs-í]	'il a fait mal'
ɔ	[sɔ́lɔ́]	'tailler imp.'
	[tɔ̀kɔ́]	'se quereller'
o	[tóká]	'puiser de l'eau'
	[sòdzá]/[à-sòd-í]	'devenir jaune, rouge imp' ('il est devenu rouge')
u	[súká]	's'arrêter, arriver à la fin imp'
	[tùdzá]/[tùlá]	'noircir imp.'

Mbosi (Bantu C.30) Compiled from Waldschmidt 2001, and in consultation with Mbosi consultants

i	[sísɑ]	'messager imp.'
	[tìsɑ]	
e	[sésɑɑ]	'redresser imp.'
	[séβɑ]	'récolter, tirer (vin de palme) imp.'
ɛ	[sɛ́lɛ]	'progresser' imp.
	[sɛ̀rɛ]	'dire' imp.
ɑ	[sɑ́lɑ]	'travailler' imp.
	[tɑ̀rɑ]	'pousser un cri imp.'
ɔ	[sɔ́sɔɔ]	
	[tɔ̀ɔ̀sɔ]	'provoquer une dispute, taquiner' imp.
o	[sórɑ]	'déshabiller imp.'
	[sòsɑ]	'laver, nettoyer quelqu'un imp.'
u	túsɑ	'cueillir' imp.
	tùsɑ	

LuBwisi (Bantu J.20) Compiled from Tabb 2001/2004

/i/	[mà-tíítì]	‘milk’
	[kù-sììmà]	‘to thank’
/ɪ/	[kɪ̀-sɪ̂ká]	‘room, wall’
	[kʊ̀-sɪ̀ɪ̀ɣà]	‘to paint, smear’
/ɛ/ [e]	[ŋ̀-kèkì]	‘woodcutting insect’
	[kì-tèlí]	‘type of weed’
[ɛ]	[kʊ̀-tɛ́ɛ̀kà]	‘to cook’
	[kʊ̀-hɛ̀ɛ̀kà]	‘to carry’
/ɑ/ [ə]	[mʊ̀-kə́lí]	‘woman’
[ɑ]	[mʊ̀-kɑ́lɪ̀]	‘brave person’
	[mʊ̀-sɑ́ɑ́sɑ̀]	‘man’
	[kʊ̀-sɑ̀ɑ̀lɑ̀]	‘to pass’
/ɔ/ [ɔ]	[kà-sɔ̀ɔ̀là]	‘small housefly’
	[kʊ̀-lɔ́ɔ̀tà]	‘to dream’
[o]	[ǹ-dóótí]	‘dream’
	[βù-tòkì]	‘authority, power’
	[βù-sòlú]	‘spear grass’
/ʊ/	[kɪ̀tʊ́ʊ̀lɔ̀]	‘grave’
	[kʊ̀-hʊ̀ʊ̀hà]	‘to blow’
/u/	[kìì-túúbì]	‘traditional shelter’
	[mù-lùùtì]	‘girl’

Kinande (Bantu J.40) Adapted from Mutaka 2005, and in consultation with Kinande consultants

i	/ɛ-ri-hin-ɑ/	[erihíːnə]	'to be sad'
	/ɛ-ri-yir-ɑ/	[eriyíːrə]	'to dislike'
	/ɛ-ki-simi/	[ekísíːmi]	'jigger'
ɪ	/ɛ-rɪ-hɪn-ɑ/	[ɛrɪhíːnɑ]	'to fail'
	/ɔ-mʊ-sɪkɑ/	[ɔmʊsíːkɑ]	'a girl'
ɛ [e]	/ɔ-mʊ-hɛk-i/	[omuhéːçi]	'carrier'
	/ɔ-mʊ-lɛg-i/	[omúleːyi]	'a false accuser
[ɛ]	/ɛ-rɪ-hɛk-ɑ/	[ɛrɪhɛːkɑ]	'to carry'
	/ɛ-rɪ-lɛg-ɑ/	[ɛrílɛːɣɑ]	'to falsely accuse someone.'
/ɑ/ [ɑ]	/ɛ-rɪ-hɑt-ɑ/	[ɛrɪhɑːtɑ]	'to peel'
	/ɛ-rɪ-sɑt-ɑ/	[ɛrɪsɑːtɑ]	'to dance'
[ə]	/ɛ-hɪ-hɑt-i/	[ehihəːti]	'small potato peelings'
	/ɔ-mʊ-sɑt-i/	[omusəːti]	'dancer'
/ɔ/ [ɔ]	/ɛ-rɪ-sɔk-ɑ/	[ɛrɪsɔːkɑ]	'to cross'
	/ɛ-rɪ-lɔg-ɑ/	[ɛrɪlɔːɣɑ]	'to bewitch'
[o]	/ɔ-mʊ-sɔm-i/	[omusoːmi]	'reader'
	/ɔ-mʊ-lɔg-i/	[omulóːyi]	'witch' 'sorcerer'
/ʊ/	/ɛ-rɪ-hʊm-ɑ/	[ɛrɪhʊːmɑ]	'to hit with an instrument'
	/ɛ-rɪ-lʊk-ɑ/	[ɛrɪlʊːkɑ]	'to weave'
/u/	/ɛ-ri-hum-ɑ/	[eríhuːmɑ]	'to migrate'
	/ɔ-mʊ-hʊm-i/	[omuhúːmi]	'a hitter'

Ekiti-Yoruba (Defoid: Edekiri) Compiled with the assistance of the Ekiti language consultants

i	èbi	‘guilt’
	òbí	‘parent’
e	òde	‘open space’
	èté	‘lip’
ɛ	ʊdɛ	‘brass’
	ɔdɛ	‘hunter’
ɑ	ɑtɑ	‘pepper’
	itɑ	‘pepper’
	ʊgbɑ́	‘calabash’
ɔ	tɔ	‘jump’
	ɪtɔ́	‘saliva’
o	ètò	‘orderly arrangement’
	ugbó	‘bush’
u	etu	‘Maxwell’s duiker’
	òkú	‘corpse’

Ifè (Defoid: Edikiri) Compiled from Gardner and Graveling 2000

i	ti	‘to come from’
	etí	‘ear’
e	se	‘to gather’
	sé	‘to close’
	sè	‘to boil’
ɛ	sɛ	‘to be bitter’
	sɛ́ɛ́	idiophone
	tɛ̀ɛ̀	3rd singular
ɑ	sɑ	‘to tell’
	sɑ́	‘to fear’
	tɑ	‘to throw’
ɔ	itɔ́	‘saliva’
	tɔ	‘to light’
	ɔ̀tɔ	‘serious situation, affair’
o	so	‘to attach’
	só	‘to pass gas’
	isó	‘fart’
	tó	‘to suffer’
	tò	‘to put away, tidy’
u	sú	‘to scatter’
	tu	‘to pull out’

Foodo (Kwa: Guang) Compiled with the assistance of Gray Plunkett

i	[tíː]	‘to follow’
	[pìː]	‘to surprise someone’
ɪ	[dɪ́ːsɑ́]	‘to ask’
	[tɪ̀ːlɪ̀]	‘to brand’
e	[déːsī]	‘to approve’
	[fèː]	‘to say’
ɛ	[tɛ́ː]	‘to forgive’
	[sɛ̀ː]	‘to cut hair’
ɑ	[sɑ́ː]	‘to draw (water)’
	[tɑ̀ː]	‘to drip’
ɔ	[tɔ́ːsí]	‘to gather (small quantity)’
	[sɔ̀ː]	‘to buy’
o	[sóːlí]	‘to gather’
	[tóːlí]	‘to make a mistake’
ʊ	[sʊ́ːlɪ̂]	‘to inhale quickly’
	[sʊ̀ː]	‘to set a trap’
u	[súː]	‘to spit’
	[tùː]	‘to pay’

Ikposo (Kwa: Left Bank) Compiled from a personal database

i	[íti]	'sorcery'
	[ési]	'fetish'
ɪ	[ítɪ]	'time'
	[ɔ́sɪ]	'woman'
e	[ìté]	'donkey'
	[úse]	'message'
ɛ	[ɑ́tɛ]	'3s took'
	[ɔsɛ]	'guinea fowl'
ə	[útə́]	'saliva'
	[púsə]	'small sponge'
ɑ	[ʊ́tɑ̄]	'egg plant'
	[ɑsɑ]	'possess' nominalized form
ɔ	[ɛtɔ]	'latrine'
	[ɑ́zɔ]	'3s call'
o	[íto]	'circumcision'
	[izo]	'clay'
ʊ	[ɛtʊ]	'body'
	[ɑ́sʊ]	'axe'
u	[etu]	'gun'
	[esu]	'suffer' nominalized form

Tuwuli (Kwa: Left Bank) Compiled from unpublished Harley manuscripts and consultation with Alex Dotse

i	[tìtì]	'from ancient times'
	[fì]	'fire'
e	[tìtè]	'land, earth, soil'
	[òtʃé]	'tree'
ɛ	[fɔ́fɛ̀]	'rice' pl.
	[lɛ̀pɛ́tɛ]	'vulture'
ɑ	[kɔ̀bɑ̀]	'farm'
	[kɑ̀sɑ́]	'wide'
ɔ	[ɔ̀tɔ̀]	'mountain'
	[ɔ̀tɔ̂]	'home'
o	[kɑvô]	'wood'
	[lùkpó]	'stool'
u	[kútû]	'soup'
	[lùpú]	'stomach'

REFERENCES

Afola-Amey, Ufuale Christine. 1995. Etude géolinguistique du pays kposo. Mémoire du Diplôme d'Etudes Approfondies, Université du Bénin.

Adjekum, Grace, Mary E. Holman and Thomas W. Holman. 1993. Phonological processes in Anufɔ. Language Monographs, 2. Legon: Institute of African Studies, University of Ghana.

Akinkugbe, Olufẹmi Odutayọ. 1978. A comparative phonology of Yoruba dialects, Iṣẹkiri, and Igala, Doctoral Dissertation, University of Ibadan, Nigeria.

Anderson, Coleen G. 1999. ATR vowel harmony in Akposso. Studies in African Linguistics 28 (2), 185-214.

Anderson, Coleen G. 2003. In search of an acoustic correlate of [ATR] in Ikposo. In John Mugane (ed.), Trends in African Linguistics, vol. 8. Tenton: Africa World Press.

Anderson, Coleen G. 2007. F1 and center of gravity interplay in the maintenance of phonological height within a statistical model of a communal grammar: The case of Foodo [ATR] acoustics. UTA Working Papers in Linguistics 2006-2007, 2-29.

Anderson, Coleen, Lois Dozeman, Deborah Hatfield and Angela Kluge. 1992. A sociolinguistic survey among the Akposso. MS, Lomé, Togo: Summer Institute of Linguistics.

Archangeli, Diana and Douglas Pulleyblank. 1989. Yoruba vowel harmony. Linguistic Inquiry 20:2, 173-217.

Archangeli, Diana and Douglas Pulleyblank. 1994. Grounded Phonology. Cambridge: MIT Press.

Archangeli, Diana and Douglas Pulleyblank. 2002. Kinande vowel harmony: domains, grounded conditions, and one-sided alignment. Phonology 19:139-188.

Armstrong, Robert G. 1985. The tenth vowel in proto-Kwa. Journal of West African Languaegs 15, 1:104-110.

Atta, Samuel Ebongkome. 1993. The phonology of Lukundu (Bakundu). Post-graduate diploma thesis (mémoire de maîtrise en linguistique). Department of African Languages and Linguistics, Faculty of Letters and Social Sciences, University of Yaoundé.

Bamgbose, A. 1967. Vowel harmony in Yoruba. Journal of African Languages 6, 268-273.

Bastin, Yvonne. 2003. The Interlacustrine zone (Zone J). In Derek Nurse and Gérard Philippson (eds.), The Bantu languages. New York: Routledge.

Bedrov, Ja.A., L.A. Chistovich and R.L. Sheikin. 1976. Frequency location of the 'center of gravity' of the formants as the useful parameter in vowel perception. Akust. Zh. 24, 480-486.

Bennet, P. R. and P. S. Sterk. 1977. South-Central Niger-Congo: A re-classification. In Studies in African Linguistics 8, 241-273.

Berry, J. 1952. Structural affinities of the Volta River languages and their significance for linguistic classification. Ph.D. dissertation. University of London.

Berry, J. 1955. Some notes on the phonology of the Nzema and Ahanta dialects. Bulletin of the School of Oriental and African Studies, 17:160-165.

Berry, J. 1957. Vowel harmony in Twi, Bulletin of the School of Oriental and African Studies, 19, 124-130.

Bruens, A. 1937. A grammar of Lundu. London: St Joseph's Society, Mill Hill Mission.

Bruens, A. 1948. Het Londo (Brits-Kameroen). Kongo-Overzee, 14:87-106.

Burquest, Donald A. 2005. Phonological analysis: A functional approach. 3rd Edition. Dallas: SIL International.

Casali, Roderic F. 1997. Cross-height vowel harmony in Ghanaian languages. GILLBT working paper.

Casali, Roderic F. 2003. [ATR] value asymmetries and underlying vowel inventory structure in Niger-Congo and Nilo-Saharan. Linguistic Typology 7, 307-382.

Casali, Roderic F. 2006. Preliminary observations on the phonology and noun class system of Animere. Paper presented at the 37th Annual Conference on African Linguistics, University of Oregon, April 8, 2006

Chistovich, Ludmilla A. and Valentina V. Lublinskaya. 1979. The 'center of gravity' effect in vowel spectra and critical distance between the formants: Psychoacoustical study of the perception of vowel-like stimuli. Hearing Research 1, 185-195.

Clements, George N. 1974. Vowel harmony in Ewe. Studies in African Linguistics 5:281-301.

Clements, George N. 1991. Vowel height assimilation in Bantu languages. Working Papers of the Cornell Phonetics Laboratory 5:37-76.

Cole, Jennifer and Charles Kisseberth (eds.) 1994. Perspectives in phonology. Stanford: Center for the Study of Language and Information.

Cooper, William E. and John M. Sorenson. 1981. Fundamental frequency in sentence production. New York : Springer-Verlag.

Cullen, Wendy R. 1999. Tense and aspect in Lubwisi narrative discourse. The University of Texas at Arlington. Ph.D. dissertation.

Delattre, P., A.M. Liberman, F.S. Cooper and L.J. Gerstman. 1952. An experimental study of the acoustic determinants of vowel colour: observations on one- and two-formant vowels synthesis from spectrographic patterns. Word 8, 195-210.

Dieu, Michel, and Patrick Renaud. 1939. Atlas linguistique de l'Afrique Centrale (ALAC): Atlas linguistique du Cameroun (ALCAM). Situation linguistique en Afrique centrale: Inventaire préliminaire: Le Cameroun. Paris: ACCT (Agence de Coopération Culturelle et Technique) and Yaoundé: CERDOTOLA (Centre Régional de Recherche et de Documentation sur les Traditions Orales et pour le Développement des Langues Africaines) and DGRST (Délégation Générale à la Recherche Scientifique et Technique).

Edmondson, Jerold A. and John H. Esling. 2006a. The valves of the throat and their functioning in tone, vocal register and stress: laryngoscopic case studies. Phonology 23, 157-191.

Edmondson, Jerold A. and John H. Esling. 2006b. The laryngeal basis for the freature [-ATR]. Paper for delivery at the Annual Conference on African Linguistics, University of Oregon, Euguene. April 9, 2006.

Edmondson, Jerold A., Cecile Padayodi, David J. Silva, and John H. Esling. 2008. The laryngeal basis of the feature [ATR]. Unpublished manuscript.

Edmondson Jerold A. and Li Shaoni. 1994. Voice quality and voice quality change in the Bai language of Yunnan Province. Linguistics of the Tibeto-Burman Area 17(2): 49-68.

Esling, John H. and Jimmy G. Harris. 2005. States of the glottis: an articulatory phonetic model based on laryngoscopic observations. In William J. Hardcastle & Janet Mackenzie Beck (eds.) A figure of speech: a Festschrift for John Laver. Mahwah, NJ: Erlbaum. 347-383.

Fant, Gunnar. 1960. Acoustic Theory of Speech Production. The Hauge: Mouton & Co.

Fant, Gunnar. 1972. Vocal tract wall effects, losses and resonance bandwidths. Speech Transmission Laboratory Quarterly Progress and Status Report, No. 203, 28-52.

Forrest, Karen, Gary Weismer, Paul Milenkovic, and Ronald N. Dougall. 1988. Statistical analysis of word-initial voiceless obstruents: Preliminary data. Journal of the Acoustical Society of America 84(1) 115-123.

Fresco, E. 1970. Topics in Yoruba dialect phonology. Studies in African Linguistics, Supplement 1.

Friesen, Dan. 2002. Oroko orthography development: Linguistic and sociolinguistic factors. Unpublished master's thesis, University of North Dakota, Grand Forks.

Friesen, Dan and Lisa Friesen. 2001. Extendibility survey of Oroko (Orɔkɔ). Unpublished manuscript.

Friesen, Lisa. 2002. Valence change and Oroko verb morphology (Mbonge dialect). Unpublished master's thesis, University of North Dakota, Grand Forks.

Friesen, Lisa. 2004. Oroko grammar sketch. Unpublished manuscript.

Fulop, S.A., E. Kari and P. Ladefoged. 1998. An acoustic study of the tongue root contrats in Degema vowels. Phonetica, 55, 80-98.

Fujimura, Osamu & Jan Lindqvist. 1971. Sweep-tone measurements of vocal-tract characteristics. Journal of the Acoustical Society of America 49(2), 541-558.

Gardner, Mary and Elizabeth Graveling, editors. 2000. *Oŋù-afɔ̀ ŋa ńfɛ̂ òŋu okpì-ŋà ŋa ńfãrãsé* (Dictionnaire Ifè – Français).

Gick, Bryan. 2002. The use of ultrasound for linguistic phonetic fieldwork. Journal of the International Phonetic Association. 32:2, 113-122

Gick, Bryan, Douglas Pulleyblank and Ngessimo Mutaka. 2006. Low vowels and transparency in Kinande vowel harmony. Phonology 23:1-20.

Gordon, Matthew, Paul Barthmaier and Kathy Sands. 2002. A cross-linguistic acoustic study of voiceless fricatives. Journal of the International Phonetic Association 32:141-174.

Gordon, Raymond G., Jr. (ed.) 2005. Ethnologue: Languages of the World, Fifteenth edition. Dallas, Tex.: SIL International. Online version: http://www.ethnologue.com/.

Guion, Susan G., Mark W. Post & Doris L. Payne. 2004. Phonetic correlates of tongue root vowel contrasts in Maa. Journal of Phonetics 32, 517-542.

Guthrie, Malcom. 1948. The classification of the Bantu languages. Oxford University Press, London.

Guthrie, Malcom. 1953. The Bantu languages of western equatorial Africa. London: Oxford University Press for the International African Institute.

Guthrie, Malcom. 1967/71. Comparative Bantu. 4 vols. Farnborough: Gregg International Publishers.

Halle, Morris & Kenneth Stevens. 1969. On the feature “Advanced Tongue Root”. MIT Research Laboratory of Electronics Quarterly Progress Report, 94, 209-215.

Hansford, Keir Lewis. 1990. A grammar of Chumburung. Ph.D. Dissertation. The University of London.

Harley, Matthew. W. 2005. A descriptive grammar of Tuwuli, a Kwa language of Ghana. Dissertation. University of London.

Henderson, Eugénie J. A. 1952. The main features of Cambodian pronunciation. Bulletin of the School of Oriental and African Studies 14.1:149-174.

Henson, Bonnie J. To appear. Defining the word in Kol. In Proceedings of the 38th Annual Conference of African Languages University of Florida, Gainesville.

Hess, Susan. 1992. Assimilatory effects in a vowel harmony system: an acoustic analysis of advanced tongue root in Akan. Journal of Phonetics 20, 475-492.

Hinnebusch, Thomas J. Bantu. 1989. In The Niger-Congo Languages. John Bendor-Samuel, ed. University Press of America, Lanham, London.

Hyman, Larry M. 1989. Advanced tongue root in Kinande. Ms., University of California, Berkeley.

Hyman. Larry M. 1999. The historical interpretation of vowel harmony in Bantu. In Bantu Historical Linguistics: Theoretical and Empirical Perspectives. Jean-Marie Hombert and Larry M. Hyman, eds. Stanford: CSLI Publications, 235-295.

Hyman, Larry M. 2002. Is there right-to-left bias in vowel harmony? Paper presented at the 9th International Phonology Meeting, Vienna, Nov. 1, 2002.

Hyman, Larry M. 2003. Segmental phonology. In The Bantu Languages. Derek Nurse and Gérard Philippson, eds. New York: Routledge, 42-58.

Jacobson, Leon C. 1978. DhoLuo vowel harmony: a phonetic investigation. UCLA Working Papers in Phonetics 43.

Johnston, H. 1919/1922. Vols. 1-2. A comparative study of the Bantu and semi-Bantu languages. Oxford: Clarendon.

Jongman, Allard, Ratree Wayland and Serena Wong. 2000. Acoustic characteristics of English fricatives. Journal of the Acoustical Society of America 108(3) 1252-1263.

Keating, Patricia A. 1985. Universal phonetics and the organization of grammars. In V.A. Fromkin (ed.), Phonetic linguistics: Essays in honor of Peter Ladefoged. Orlando, FL: Academic Press, 115-132.

Kenstowcicz, Michael. 1994. Phonology in generative grammar. Oxford: Blackwell.

Kingston, John, Neil A. Macmillan, Laura Walsh Dickey, Rachel Thorburn and Christine Bartels. 1997. Integrality in the perception of tongue root position and voice quality in vowels. Journal of the Acoustical Society of America 101(3), 1696-1709.

Klaver, Marquita. 1988/2001. A descriptive grammar of the Ifè language. Unpublished manuscript. SIL-Togo.

Kleiner, Renate. 1989. Phonology notes of Gɩdɩrɛ, the language of the Adele V/R. MS, Ghana Institute of Linguistics, Literacy and Bible Translation.

Kohler, Anna. 1981/2000. Le ton en ifè. Unpublished manuscript. SIL-Togo.

Kohler, Anna. 1984/2000. Vowel and tone sandhi in Ifè. Unpublished manuscript. SIL-Togo.

Koloni, Jean. 1971. Eléments de morphologie et de vocabulaire de la language enya. Mémoire. Kinshasa : Université Lovanium.

Kuperus, Juliana. 1985. The Londo word: its phonological and morphological structure. Tervuren, Belgique: Musée Royal de l'Afrique Centrale.

Kutsch Lojenga, Constance. 1999. The vowel system of Lika: First impressions. Paper presented at the 29th Colloquium of African Languages and Linguistics, University of Leiden, 29 August – 1 September 1999.

Kutsch Lojenga, Constance. 2003. Bila. In The Bantu Languages. Derek Nurse and Gérard Philippson, eds. London & New York: Routledge.

Kutsch Lojenga, Constance and Elizabeth Hood. 1982. L'Attie. In Georges Hérault (ed.), Atlas des langues kwa de Côte d'Ivoire, Vol. 1 : Monographies. Abidjan : Université d'Abidjan, Institut de Linguistique Appliquée, and Agence de Coopération Culturelle et Technique.

Ladefoged, Peter. 1971. Preliminaries to linguistic phonetics. Chicago: University Press.

Ladefoged, Peter. 1972. Phonological features and their phonetic correlates. Journal of the International Phonetic Association 2.2-12.

Ladefoged, Peter. 2003. Phonetic data analysis: an introduction to fieldwork and instrumental techniques. Malden: Blackwell Publishing.

Leitch, Myles. 1996. Vowel harmonies of the Congo basin: An optimality theory analysis of variation in the Bantu zone C. Ph.D. dissertation, University of British Columbia.

Lindblom, Bjorn and S. J. Moon. 1988. Formant undershoot in clear and citation-form speech. PERILUS 8, 21-33.

Lindau, Mona. 1975. Features for vowels. UCLA Working Papers in Phonetics 30.16-21.

Lindau, Mona. 1976. Larynx height in Kwa. UCLA Working Papers in Phonetics 31.53-61.

Lindau, Mona. 1978. Vowel features. Language 54, 541-63.

Lindau-Webb, Mona. 1987. Tongue mechanisms in Akan and Luo. UCLA Working Papers in Phonetics 68:46-57.

Lisker, Leigh and Arthur S. Abramson. 1964. A cross-language study of voicing in initial stops: Acoustical measurements. Word 20, 384-422.

Local, John and Ken Lodge. 1996. Another travesty of representation: phonological representation and phonetic interpretation of ATR harmony in Kalenjin. York Papers in Linguistics 17:77-117.

Maganga, Clement and Thilo C. Schadeberg. 1992. Kinyamwezi: grammar, texts, vocabulary. Köln: Koppe.

Maho, Jouni. 2003. A classification of the Bantu languages: an update of Guthrie's referential system. In *The Bantu languages*. Derek Nurse and Gérard Philippson, eds. pp. 639-651. Rutledge: New York.

Meeussen, A.E. 1980 [1969]. Bantu Lexical Reconstructions. Tervuren: Koninklijk Museum voor Midden-Afrika.

Mutaka, M. Ngessimo. 1991. The tense marker –Ire in the Kinande verbal stem: Evidence for a stratatally organized phonology. In F. Katamba (ed.), Lacustrine Bantu Phonology. Afrikanistische Arbetspapiere 25:157-73.

Mutaka, M. Ngessimo. 1994 [1990]. The lexical tonology of Kinande. Munich and New Castle: Lincom-Europa.

Mutaka, Ngessimo M. 1995. Vowel harmony in Kinande. Journal of West African Languages 25.2:42-55.

Norlin, K. 1983. Acoustic analysis of fricatives in Cairo Arabic. Working Papers (Lund University Department of Linguistics) 25, 113-137.

Paluku, André Mbula. 1998. Description grammatical du Kitalinga: (langue Bantu du Nord-Est du Zaïre. München; Newcastle: LINCOM Europa.

Painter, Colin. 1972. Phonological features underlying vowel harmony loss in certain West African languages. In Colin Painter (ed.), Fourteen papers on Gwa and fifty-two texts in Gwa, 30-33. Collected language notes 12. Legon: Insititute of African Studies, University of Ghana.

Parkinson, Frederick. 1996. The representation of vowel height in phonology. Ohio State University dissertation.

Plunkett, Gray C. 1991. The tone system of Foodo nouns. University of North Dakota Masters Thesis.

Przezdziecki, Marek A. 2005. Vowel harmony and coarticulation in three dialects of Yoruba: Phonetics determining phonology. Ph.D. dissertation. Cornell University.

Ring, J. A. 1995. Revisiting the Central Volta Region: Avatime/Santrokofi/Bowiri. In Papers from the seminar week of the Ghana Institute of Linguistics, Literacy and Bible Translation, Tamale, 30 Jan. – 3 Feb., 1995, 119-128. Tamale: GILLBT Press.

Roberts, J. R. Introduction to phonology. Manuscript. Summer Institute of Linguistics, Horsleys Green, UK.

Schlindwein, D. 1987. P-bearing units: A study of Kinande vowel harmony. In Proceedings of NELS 17, 551-567. GLSA, University of Massachusetts, Amherst.

Schuh, Russell. 1995. Aspects of Avatime phonology. Studies in African Linguistics 24:31-67.

Shu, Abedhego Che. 1993. The noun class system of Oroko east. Post-graduate diploma thesis (mémoire de maîtrise en linguistique). Department of African Languages and Linguistics, Faculty of Letters and Social Sciences, University of Yaoundé.

Snider, Keith L. 1989. The vowels of proto-Guang. Journal of West African Languages XIX, 2:29-50.

Snider, Keith L. 1990. Studies in Guang phonology. Leiden, Netherlands: University of Leiden dissertation.

Spa, Jaap J. 1973. Traits et tons en enya : phonologie générative d'une language bantoue. Tervuren : Musée Royal de l'Afrique Centrale.

Stappers, Leo. 1973. Esquisse de la langue mituku, Annales No. 80. Tervuren: Musée Royal de l'Afrique Centrale.

Steriade, Donca. 1995. Underspecification and markedness. J. Goldsmith (ed.) The handbook of phonological theory, 114-174. Blackwells: Oxford.

Stevens, K. N. & A. S. House. 1963. Perturbation of vowel articulations by consonantal context: An acoustical study. Journal of Speech and Hearing Research, 6, 111-128.

Stewart, John M. 1967. Tongue root position in Akan vowel harmony. Phonetica 16, 185-204.

Stewart, John M. 1970. Tongue root position in the Volta-Comoe languages and its significance for the reconstruction of the original Bantu vowel sounds. African Languages Studies 11.340-350.

Stewart, John M. 1983. The high unadvanced vowels of Proto-Tano-Congo. Journal of West African Languages 13:19-36.

Stewart, John M. 1989. Kwa. In The Niger-Congo Languages. J. Bender-Samuel (ed.), 216-245. Lanham: University Press of America.

Stewart, John M. 1998. An explanation of Bantu vowel height harmony in terms of a pre-Bantu nasalized vowel lowering. Paper presented at the 28th Colloquium on African Languages, Leiden.

Storch, Anne and Yao Koffi. 2000. Noun classes and alternation in Akebu (Kəgbərākə̂). In Antje Meissner & Anne Storch (eds.) Nominal classification in African languages. FAB, 12.79-98. Köln: Rudiger Koppe.

Struck, R. 1912. Einige Sudan-Wortstämme. In Zeitschrift für Kolonialschrachen 2, 233-253, 309-323.

Svantesson, J-O. 1986. Acoustic analysis of Chinese fricatives and affricates. Journal of Chinese Linguistics 14, 53-70.

Tabb, Waller C. (Jr.). 1993. A sociolinguistic survey of six Bantu languages of Uganda. M.A. Thesis, Makerere University, Kampala.

Tabb, Waller C. (Jr.). 2001, 2004. LuBwisi phonology survey. Unpublished manuscript. SIL-Uganda.

Tiede, Mark K. 1996. An MRI-based study of pharyngeal volume contrasts in Akan and English. Journal of Phonetics 24:399-421.

Tucker, A.N. and M.A. Bryon. 1957. Linguistic survey of the northern Bantu borderland. Oxford: International African Institute.

Valinande, N.K. 1984. The structure of Kinande. Washington: Georgetown University.

Welmers, William. 1973. African language structures. Berkeley and Los Angeles: University of California Press.

Westermann, Diedrich. 1930. A study of the Ewe language. Translated by A. L. Bickford-Smith. London: Oxford University Press.

Williamson, Kay and Roger Blench. 2000. Niger-Congo. In African Languages: An Introduction. B. Heine and D. Nurse (eds.), 11-42. Cambridge: Cambridge University Press.

Zsiga, Elizabeth Cook. 1993. Features, gestures, and the temporal aspects of phonological organization. Doctoral dissertation, Yale University.

http://en.wikipedia.org/wiki/Ekiti_State (9/8/2007 4:56:59 PM)

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