National Library of Canada | Bibliothèque nationale du Canada

Acquisitions and Bibliographic Services Branch | Direction des acquisitions et des services bibliographiques

395 Wellington Street
Ottawa, Ontario
K1A 0N4 | 395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

UNIVERSITY OF ALBERTA

ACOUSTIC CORRELATES OF ADVANCED TONGUE ROOT

BY

RADECKA A. G. APPIAH-PADI

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

IN

SPEECH PERCEPTION AND PRODUCTION

DEPARTMENT OF LINGUISTICS

EDMONTON, ALBERTA

SPRING, 1994

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: Radecka A.G. Appiah-Padi

TITLE OF THESIS: Acoustic correlates of Advanced Tongue Root

DEGREE: M. Sc.

YEAR THIS DEGREE GRANTED: 1994

RAppadiy

(Student's signature)

P.O. Box 9818

Airport - Accra

Ghana

(Student's permanent address)

Date: 6/1/94

ISBN 0-612-11146-6

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled ACOUSTIC CORRELATES OF ADVANCE TONGUE ROOT submitted by Radecka A.G. Appiah-Padi in partial fulfillment of the requirements for the degree of Master of Science in Speech Production and Perception.

Dr. T.M. Nearey (Supervisor)

Dr. B.L. Derwing

Dr. M. Hodge

30 Dec 93

Date

DEDICATION

To Steve and Maafio

ABSTRACT

In determining the acoustic correlates of the advanced tongue root feature [ATR], researchers have generally tended to focus on one property of the entire articulatory movement underlying the feature. Consequently, different researchers have often come to different conclusions. Hess (1987, 1992) has proposed the first formant bandwidth as acoustic correlate of ATR. Given that studies of Indo-European languages indicate that the bandwidths of the formants do not markedly distinguish different vowels and also are secondary to the accurate perception of vowel quality, it expected that if indeed this relatively "exotic" parameter is a reliable litmus test for ATR, it would hold for many speakers of the language. This thesis explored the reliability of the first formant bandwidth as an acoustic marker of ATR in Akan vowels and also the nature of the acoustic parameters that mark the advanced tongue root feature. Nine male native speakers of the Asante dialect of Akan were asked to read list of 108 words containing tokens of the 10 vowel of Akan. The vowels were recorded, digitized and analyzed. The results showed that first formant bandwidth alone is not a good predictor of ATR because it does not generalize over several speakers. Also, the ATR feature that serves as the phonetic bases of this harmony is not marked by a single acoustic parameter as has been proposed by Stevens and Halle (1969), Lindblom & Sundberg (1971), Lindau (1979), and Hess (1987, 1992), but rather a combination of correlates which include first and second formant frequencies/amplitudes and duration. The nature of the combinations varies from vowel to vowel and also from speaker to speaker. Given these results, it is suggested that to give a proper account of the nature of the acoustic correlate of ATR, the role of all these parameters must be considered.

ACKNOWLEDGMENT

My sincerest gratitude to my supervisor Dr. T.M. Nearey for his guidance and direction throughout the writing of this thesis. I would also like to thank my other committee members, Dr. B.L. Derwing and Dr. M.M. Hodge for the very useful criticisms and suggestions they offered.

To my friends and colleagues, Darrell and Andrea, I say a very big thank you for all the support and encouragement.

My appreciation is also extended to Tom Welz, Diane Kudryk and Mary Daly of the Department of Linguistics for all the help they gave me.

The financial support of the Department of Linguistics and the American Association of University Women Educational Foundation is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

Phonological features used to describe vowel harmony have generally been assumed to be articulatorily-based. Recent studies, however, indicate that the correlates of features are not always articulatory. Although some features have acoustic correlates, others have auditory correlates, while others have combinations of these correlates. In searching for an acoustic correlate for the advanced tongue root feature [ATR], researchers have not only sought a single acoustic correlate but also have tended to focus on one property of the entire articulatory movement underlying the feature. Consequently, different researchers have often come to different conclusions. This thesis examines some of the research that has been done on the acoustic correlates of ATR and tests further some of the conclusions that have been made with regards to the acoustic nature of the [±ATR] vowel distinction in Akan vowel harmony.

This thesis is organized as follows: In chapters 1 and 2 a brief overview of Akan and its vowel harmony system is given. As well, chapter 2 contains a review of previous research done on ATR as it pertains to Akan vowel harmony. The remaining chapters of this thesis are devoted to discussing the findings of the present study, focusing, particularly, on the impact of the categorization of ATR vowels.

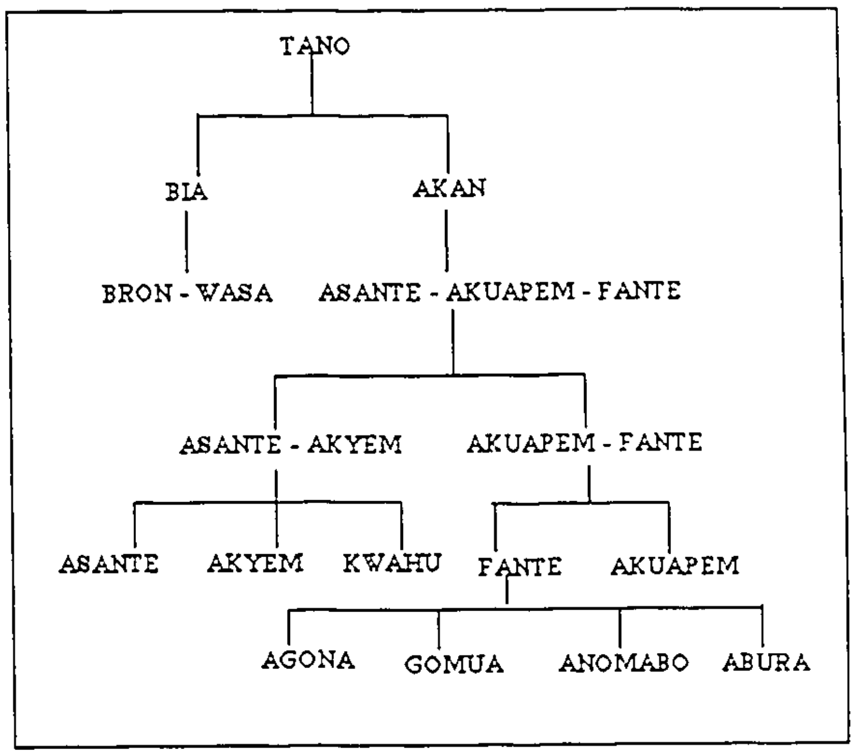
A BRIEF OVERVIEW OF AKAN PHONOLOGY AND SELECTED MORPHOLOGY

"Akan" is the name of a dialect cluster (following Westerman & Bryan, 1952) spoken in some forest and coastal areas of Ghana and Ivory Coast in West Africa. It is one of the most widely spoken languages in Ghana and is considered a prestigious language. Many words have been borrowed from it into other indigenious languages of Ghana (Dakubu, 1973). The following genetic history of Akan is a condensation of Westerman & Bryan (1952); Stewart (1966a) and Dolyphne & Kropp Dakubu (1988). Genetically, "Akan" belongs to a family of languages that has been termed differently by different researchers. Westerman and Bryan (1952) call this family of languages "Akan" and subdivide it into three co-ordinate languages, Guang, Anyi-Baule and Twi-Fante (which is still part of present-day

Akan). Greenberg (1963) also refers to the group as Akan, though he considers it as consisting of five languages, Abure, Anyi, Guan, Metyibo and Twi.

Stewart (1966a) uses the term "Volta-Comoe" to describe this language group because, according to him, the languages are spoken in an area boarded by the Volta River, on the east and the Comoe River, on the west. Stewart further subdivides the group into the Ono language group, Tano language group and Guang language group, with present day Akan belonging to the Tano group.

Figure. 1.1: DIALECTS OF PRESENT-DAY AKAN[1]



Dolphyne (1974), on the other hand, prefers the name "Volta-Bandama" because, according to her, the river on the west is the Bandama River, not the Comoe. Whatever name it is called, the genetic unity of the "Volta-Comoe" languages is well recognised.

---

[1] Figure 1 is adapted with modifications from Dolphyne & Kropp Dakubu (1988: 56)

The name "Akan" was adopted in the 1950's to refer to the Twi-Fante language cluster (where Twi refers to all the non-Fante dialects). Up until then the dialects had been treated as separate languages with individual orthographies. This may be attributed to the fact that prior to colonialism, the different ethnic groups considered themselves as "independent nations". Figure 1.1 shows the dialects of present-day Akan

In the following section the phonology of Akan is briefly discussed. The examples given are drawn mainly from the Asante dialect.

VOWELS

Akan has ten oral vowel phones, which are represented by seven letters orthographically as:

orthography : i e ɛ a ɔ o u

phones : i ɪ e ɛ (æ) a ɔ o ʊ u

[æ] occurs only in the Asante and Akuapem dialects. In other dialects, for example, Fante, /æ/ is supposed to have merged with /e/ (Dolphyne, 1988). /a/ acts as a neutral vowel in the vowel harmony systems of all the dialects except Asante and Akuapem. It may occur with vowels in either harmony groups.

NASALISATION

The oral/nasal vowel contrast occurs only after voiceless consonants. Vowel nasalisation in Akan occurs at both the phonetic or phonemic level (Schachter & Fromkin, 1968). With non-mid vowels, nasalisation is phonetic and phonemic in the following examples:

fi	"go out"	fĩ	"dirt"
sa	"dance"	sã	"finish"
tu	"throw"	tũ	"bake"
hu	"blow"	hũ	"see"

When nasalisation is phonetic, [-nasal] vowels become [+nasal] through the operation of some phonological rules (that is, assimilation of the [-nasal] to the adjacent [+nasal] segment. The adjacent sound may either be a vowel or consonant). In a vowel-to-vowel assimilation the [-nasal] vowel may either precede or follow the [+nasal] segment: /tɔ/ "buy" /tɔ̃ʊ̃/ "sell". Here the [+nasal] of the following high back vowel affects the /ɔ/. An example of a situation where the preceding vowel triggers assimilation is in the past tense form of some verbs e.g. /hũ/ " see", /-i/ "past tense marker", /hũĩ/ "saw".

Vowel and nasal consonant assimilation occur only when the [-nasal] vowel precedes the nasal consonant and the vowel is a high vowel:

[dũm]	extinguish	[fam]	embrace
[tĩm]	get stuck	[somu]	hold it
[sʊ̃m]	serve		

LENGHTENING

Vowel lengthening is used phonemically in Akan, but this is not extensive in the language. It usually occurs in mono-morphemic words and in word final position:

/pi/	"to thicken"	/pi:/	"many"
/da/	"day"	/da:/	"everyday"

Lengthening may also occur when a word ending with the mid vowels /e, ɛ, o, ɔ/ or the low vowel /a/ is followed by another word beginning with a vowel. In rapid speech the final vowel of the first word is dropped and the initial vowel of the following word is lengthened:

tɪtɛ anoma no	"stalk the bird"	/tɪta:noma nʊ/
fa ɛboɔ no	"take the stone"	/fɛ:bʊɔ nʊ/
watɔ aba	"he bought it and brought it"	/wata:ba/

OTHER DISTRIBUTIONAL PROPERTIES

All vowels may occur medially or in word final positions. As stated earlier, [æ] occurs mainly in the Asante and Akuapem dialects and only before syllables containing /u/, /i/ and /o/. Only non-high vowels may occur in word-initial positions. A further restriction is placed on /e/ and /ɛ/ in Asante. They only occur in word initial position when a word beginning with a nasal consonant is in emphatic speech or citation form:

nsuo →→→ ensuo "water"

mpa →→→ ɛmpa "bed"

CONSONANTS

Akan has been analyzed by Dolphyne (1988) as having 34 phonetic consonants which are represented orthographically with 16 letters of the alphabet (Appendix 1)

Table1.1: DISTRIBUTION OF CONSONANTS[2]

	lab'al	pal'al	alveolar	palatal	velar & glottal	lab'ised palatal	lab'ised velar & glottal
plosive & aff'cate	p b		t t͡s d d͡z	tɕ dʑ	k g	tɕʷ dʑʷ	kʷ gʷ
fricative	f		s sʷ s'	ɕ	h	ɕʷ	hʷ
nasal	m		n	ɲ	ŋ	ɲʷ	ŋʷ
glide	w	y					
lateral & trill			l r				

2 Modifications made to original chart include: the use of phonetic symbols; division of "back" class into palatal/velar & glottal class; and labialised palatal/labialised velar & glottal class

GENERAL DISTRIBUTION

All consonants may occur in word-initial position. However, /ŋ/ and /r/ cannot occur in the initial position of noun, verb, or adjective roots. Only nasals and some glides may occur in word-final position Words that end in /ŋ/ and /n/ in the Fante-Akuapem dialects have nasalised vowel endings in Asante, Akyem and Kwahu. Table 1.1 (adapted from Dolphyne, 1988: 48) shows the consonants according to distribution. Phones that are in complementary distribution are in the same cell in the Table.

The distribution of the consonants may thus be summarized as follows:

a. The alternation between alveolar consonants [d, d͡z] and also between [t, t͡s] occurs only in the Fante dialects. The affricates occur before high front vowels while the plosive occur before all other vowels:

[it͡sir]	"head"	[tɔ]	"buy"
[t͡sɪʷ]	"pluck"	[kɛtɛ]	"mat"
[d͡zɪ]	"eat"	[duku]	"scarf"

The contrast between the alveolar fricatives /s, s^w, s^y/ is very limited:

/sʷa/	"be small"	/sʸã/	"be suspended"
/sã/	"be finished"		

b. Non-labialised palatal consonants (except /ɲ/ and /dʑ/) occur only before front vowels. They are in complementary distribution with non-labialised velar and glottal consonants:

[kuta]	"to hold"	[tɕɪ]	"catch/fry"
[kɔ]	"to go"	[ætɕi]	"behind"
[gʊ]	"to soften"		
[hʊ]	"to grill"		

/ɲ / and /dʑ/ occur before the central vowel /a/ and front vowels:

[dʑaɪ]	"stop"	[ɲãmɪ]	"God"
[dʑidi]	"to believe"	[ɲin]	"grow"

Labialised palatals are in complementary distribution with labialised velars and glottals. The former occur before front and back vowels and the latter, before /a/.

c. Glides occur only preceeding or following oral vowels. The labial-velar glide [w] is in complementary distribution with the labial-palatal glide [y]. [y] occurs before front vowels and [w] before back vowels and the central vowel [a]:

[wʊ]	"give birth"	[yɪ]	"chew"
[awarɪ]	"marriage"	[yia]	"steal"
[ɔwɔ]	"snake"		

d. The alveolar lateral /l/ occurs mainly in loan words. In some dialects, for example, Asante and Akyem, it is in free variation with /r/ and sometimes /d/:

(AS) [akɔda:] [akɔla:] [akɔra:] "child"

/r/ is a voiced alveolar trill in the Akuapem dialect and an alveolar glide in the Fante and Asante dialects.

TONE

Akan is a register tone language with two basic tones, high [´] and low [`]. Both tones are produced on a relatively level pitch. The syllable is the tone bearing unit in Akan. In Section 1.5 the structure of the phonological syllable in Akan is discussed. A syllabic vowel or nasal carries the tone:

/òtú/	"he flies"	/pápá/	"good"
/pìpà/	"wipe"	/m̩̀pá/	"bed"

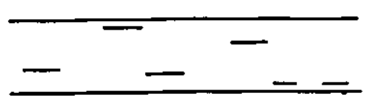
There are a few instances in the language when gliding pitches occur on diphthongs, long vowels or a sonorant and a preceding vowel.

DOWNSTEP AND DOWNDRIFT

In any H-L-H-L . . . sequence the second high tone is downstepped, (Andoh-Kumi, 1979; Dolphyne, 1988), that is, it is marginally lower in pitch than the preceding high tone. In Akan, there are three types of downstep high tones. These are often described as Automatic, non-Automatic and Lexical downstep.

Automatic downstepping occurs when a high tone is immediately preceded by a low tone:

pàpá kwàsí pápá "Papa Kwasi's fan"



With non-Automatic downstep, the triggering low tone is absent and the symbol (!) is used to mark the syllable containing the downstepped high tone:

kwàsí, àdú → → → kwàsí á!dú "the name of a boy"
àfúa, m̀pá → → → àfúa m!pá "Afua's bed"

The low tone may be absent due to tonal assimilation. In the above examples there is a regressive assimilation of the low tone in the second word to the final high tone of the first word. In some instances, non-automatic downstep is a result of the deletion of the triggering low tone. Although the low tone has been deleted its pitch lowering effect on the high tone remains:

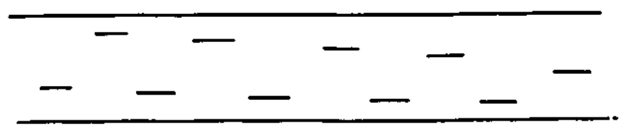
pàpá "father", ɔ̀dáń "house"
→ → → pàpá !dáń "father's house"
Dòbé, "name of a town", ɔ̀héné "chief"
→ → → Dòbé !héné "the chief of Dobe"

With lexical downstep, the downstep high tone is part of the phonemic structure of the word and not derived from a relationship between a low and high tone:

ɔ̀kɔ́!tɔ́	"crab"	àdá!ká	"box"
á!má	"name of a girl"		

The systematic lowering of tones in an entire clause results in the phenomenon refered to in the literature as "Downdrift":

Kwàsí pàpa bìsá Kòfí sìká "Kwasi's father asks Kofi for some money"



There is therefore a gradual drop in pitch for both high tones and low tones. Sometimes, the final high tone may be lower than the initial low tone.

FUNCTIONS OF TONE

Tone in Akan has either a lexical function or a grammatical function. With the lexical function, words are distinguished solely on the basis of tone:

pàpá "father" pápá "good"
pàpà "fan"

It must be noted, however, that the lexical function of tone is very much limited because there are very few words that exhibit this pattern.

The grammatical function of tone is more extensive and significant in the language. Here tone is used to distinguish different aspects and tenses of verbs:

<u>Stative</u>		<u>Habitual</u>	
bìsà	"asking"	bìsá	"asks"
<u>Optative</u>		<u>Habitual Negative</u>	
yɛ́ ḿfá	"let us take"	yɛ́ m̀fá	"we don't take"

Tone may also be used to distinguish between verbs occuring in a main clause and a subordinate clause:

mérèkàsá "I am talking" mérékásá "while I was talking"

The same is true between an interrogative and non-interrogative sentence:

ɔ̀sɛ̀ né pàpa?	"Does he look like his father?"
ɔ̀sɛ̀ né pàpá	"He looks like his father."

It is possible to distinguish between two classes of nouns, alienable and inalienable in a possessive construction, based on tonal assimilation:

a. ǹsá	"hand"	→ →	kòfí ńsá	"Kofi's hand"
b. m̀bá	"children"	→ →	kòfí ḿbá	"Kofi's children"
c. m̀pá	"bed"	→ →	kòfí ḿ!pá	"Kofi's bed"
d. sìká	"money"	→ →	kòfí sí!ká	"Kofi's money"

With the alienable nouns (c) and (d), the effect of the low tone is maintained in the second syllable. With the inalienable nouns, (a) and (b), no such effect exists.

THE SYLLABLE

As indicated earlier, the syllable is the basic tone-bearing unit. There are three different syllable structures: CV, C, V:

CV:	sa	"dance"			
	tɪ	"tear"			
C:	m/n	plural marker	as in	/m-ba/	"children"
				/n-da/	"days"
	-ŋ			/ka-ŋ/	"read"

V:	ɔ- "she/he"	as in	/ɔ-fa/	"she/he takes"
	-i/-ɪ "past tense marker"		/tu-i/	"dug"
			/dɔ-ɪ/	"weeded"

The language does not generally allow VC, CVC, CCV syllables (Dolphyne, 1988). Although one comes across words like /sra/ "smear", /kra/ "take leave of" with a CCV syllable structure in rapid speech, in emphatic speech, these syllables have a CVCV structure with the first vowel being a high front vowel and second consonant being /r/. When the initial vowel is elided, the /r/ carries its tone.

WORD FORMATION

Akan words consist of roots and affixes. These are based on different syllable combinations.

AFFIXES AND ROOTS

Prefixes and suffixes are used very extensively in Akan and have many grammatical functions (Dolphyne 1988). They are used to mark nominal forms. The nominaliser prefixes are /e, ɛ, ɔ, o, i, ɪ/ and nasals. These prefixes are marked with low tones:

hia	"to need"	o-hia	"poverty"
dɔm	"to team up"	ɛ-dɔm	"crowd"
kyia	"to greet"	n-kyia	"greetings"

Some nominaliser suffixes are / i/ɪ, iɛ/ɪɛ, fo/foɛ, ni/:

prɑ	"sweep"	prɑ-ɪ	"broom"
soma	"send"	soma-fo	"messenger"
hia	"need"	hia-ni	"poor person"

Sometimes nouns are marked by a combination of prefixes and suffixes:

dom	"to favour"	ɔ-dom-fo	"benefactor"
wu	"to die"	o-wu-o	"death"

Affixes are also used to mark number. /e, ɛ, ɔ, o, i, ɪ/ are usually used to mark singular. They change to /a/ or a nasal to mark plurality.

ɔ-ba	"child"	m-ba	"children"
e-kuw	"club"	a-kuw	"clubs"

Affixes are also used to mark different tenses and aspects.

Roots may consist of one syllable or as many as four syllables. The following are some structures of roots that occur in the language, where (-) shows the syllable boundaries:

1. CV	fa	"to take"
2. CV-V	mu-a	"to close"
3. CV-C	pa-m	"to sew"
4. C-CV	n-su	"water"
5. CV-CV	ku-ta	"to hold"
6. CV-CV-C	hye-rɛ-n	"to brighten"
7. CV-C-CV	su-n-ti	"to stumble"
8. CV-CV-CV-(C)	pa-ti-ri-(w)	"to slip"

1 to 5 are the basic structures and they account for the majority of roots in the language.

REDUPLICATION AND COMPOUNDING

Reduplication and compounding are the most common processes of word formation in the language, for example:

Compounds: ani (eye) + nsuo (water) = nisuo (tears)
di (take) + bea (place) = dibea (rank, social standing)

With reduplication, part or the whole of a root or stem is repeated:

tu	"dig"	tutu	"keep on digging"
ketewa	"little"	ketekete	"very, very tiny"

In both processes the forms undergo certain phonological changes. These include:

1. Loss of final vowel or final syllable. The final vowel or syllable of the first constituent is dropped:

ɔhene	"chief"	+	kɛse	"big"	=	ɔhenkɛse	"great king"
tire	"head"	+	bɔne	"bad"	=	tibɔne	"bad luck"

2. Loss of vowel or nasal prefix. Sometimes it is the vowel or nasal prefix of the second constituent that is dropped:

nim	"know"	+	adeɛ	"thing"	=	nimdeɛ	"knowledge"
abɛ	"palmnut"	+	nkwan	"soup"	=	abɛkwan	"palmnut soup"

3. Homorganic nasal assimilation and nasalisation of voiced plosives and affricates. With homorganic nasal assimilation, the final nasal consonant of the first constituent takes on the place of articulation of the initial consonant of the second constituent:

asɛm	"case"	+	di	"settle'	=	asendi	"judgement"
kɔn	"neck"	+	pɔw	"knot"	=	kɔmpɔw	"goitre"

In the Asante and Akuapem dialects voiced plosives and affricates that occur directly after the nasals become nasalised:

asendi becomes "asenni"

4. Vowel harmony. Vowel harmony in Akan is marked by the feature 'Advanced Tongue Root' [ATR]. The feature [ATR], refers to the position the tongue root assumes during the articulation of vowels. Vowels labeled [-ATR] have the tongue root retracted and those with [+ATR] have the tongue root unretracted. Under harmony conditions, the vowels of a given word share the same ATR value, that is, they are all either [+ATR] or [-ATR]. Across morpheme and word boundaries, unadvanced [-ATR] vowels are assimilated by the advanced [+ATR] vowels. It is a regressive process.

In the next chapter a general discussion of Akan vowel harmony is presented. Some of the studies that have been done on the acoustic properties of the vowel harmony feature of Akan are reviewed.

CHAPTER TWO : LITERATURE REVIEW

VOWEL HARMONY

The term "vowel harmony" is used to describe a class of phonological processes involving vowels of a given language. These processes occur in some African and Eurasiatic languages. Vago (1980) gives a very simple but precise definition of vowel harmony, as "a law which governs the co-occurrence of vowels within a span of utterance, nearly always the word."

Under harmonic conditions the vowels of a given language are divided into separate harmonic sets and only vowels belonging to one harmonic set can co-exist within a word. The morpheme that determines the harmonic quality of a word is referred to as the controlling morpheme and a morpheme that is subjected to harmonic alternation is referred to as a controlled morpheme (Vago, 1980). In some languages the controlling morpheme occurs consistently in the roots of words (e.g., Akan, Igbo). Harmony in these languages is described as "root-controlled". In other languages the occurrence of the controlling morpheme varies, occurring either in the root or affix. In these cases harmony is described in terms of a "dominant/recessive" distinction. Here morphemes are classified as "dominant" if they cause the assimilation of other morphemes, and morphemes that are subjected to assimilation are referred to as "recessive".

Although many studies have focused on general aspects, as well as language specific aspects of vowel harmony, linguists are yet to arrive at a typology of vowel harmony that would be a restrictive yet all-encompassing characterization of all cases of the process, that is, a set of criteria that would fall out as a natural consequence of the general principles of any phonological theory (Vago, 1980). One major advantage of having this kind of typological guideline would be the impact it would have on the investigations of "new" languages. If it is determined that vowel harmony "represents a cluster of consistent properties that go together, *then* (italic added), if we were to find certain criterial ones in a new language, we could expect to find the other, consequential ones as well" (Anderson, 1980:2).

A few attempts have been made to resolve this problem. One example is by Clements (1977a). Following Ultan (1973), Clements sets out five properties which he proposes to be the basic characteristics of all vowel harmony systems. These properties are "phonetic motivatedness", root control, bidirectionality, unboundedness and non-optionality.

Clements' Typology of Vowel Harmony

According to Clements, harmonic sets are grouped and function on the basis of features that have independent phonetic motivation and validity, for example, [±round], [±ATR]. In some languages one would be hard pressed to find a phonetically motivated feature that would separate some harmonic sets. Nez Perce (Anderson, 1980), for example, has the harmonic sets [i,u,æ] and [i,o,a]. How does one explain why /i/ is in both sets? Sometimes, historical sound change may destroy the phonetic basis of harmonic sets, as is the case in Buriat Mongolian (Anderson,1980). Cases like these point to the fact that in a synchronic analysis, "phonetic motivatedness" is not a necessary condition for vowel harmony.

The root control property supposes that roots of words always contain the controlling morphemes and therefore control the direction of all related phonological processes, for example, assimilation, that occur with vowel harmony. However, as stated earlier, in some languages, morphemes are divided into "dominant" and "recessive" and in these cases the roots do not have any "privileged position".

With bidirectionality, the harmonic influence of the dominant morpheme spreads out in both directions of the morpheme. Thus in situations where harmony operated exclusively progressively or regressively the argument was that lack of any item on the left or right of the determining morpheme accounted for this behavior (Anderson, 1980). However, examples from Akan (which has regressive harmony) show that even when the dominant morpheme is preceded and followed by other morphemes the harmony process is still exclusively regressive:

/ɔ + <u>didi</u> + fʊ/	=	[odidifʊ]
"nominal + eat + nominal"		(glutton)
prefix suffix		

(the dominant morpheme is underlined)

Bidirectionality is therefore not a necessary property of vowel harmony.

According to Clements, vowel harmony affects "substantial stretches of a word (or domains)." This is the unboundedness property of the harmony process. The processes are not limited to single vowels. This appears to be quite consistent in many languages, including Akan.

The non-optionality property supposes that vowel harmony processes are obligatory. Vago (1980) and Ringen (1980) both argue to the contrary. According to them, there are certain Hungarian words which have two optional harmonic variants. Also the process of harmony does not apply to neutral vowels, for example, /a/ in Akan.

Although the characteristics discussed above describe vowel harmony to a certain degree, it is apparent that Clements fails to lay out an "all encompassing characterization" for vowel harmony.

TYPES OF VOWEL HARMONY

Generally articulatory-based features have been used to describe the different types of vowel harmony (Lindau, 1975,1979). The three basic types of harmony generally discussed in the literature are:

(a) Labial harmony (Aoki,1968; Vago,1980; Anderson,1980)

(b) Palatal harmony (Aoki,1968; Vago,1980, Anderson,1980)

(c) Tongue root harmony (Ladefoged,1964; Stewart, 1967; Lindau, 1979)

Labial harmony occurs generally in Altaic and Uralic languages. It is characterized by the feature [+ round]. Canonical examples of this harmony type are found in Turkish. A high vowel occurring after an initial syllable becomes [+round] if the vowel in the preceding syllable is [+round]. It is an assimilatory process, with applicability that extends over the entire word.

Palatal harmony, like labial harmony, occurs mainly in Altaic and Finno-Ugric languages (Crothers & Shibatani, 1980). It is characterized by the feature [+back]. Examples of palatal harmony occur in Hungarian (Ringen, 1980). Non-neutral vowels are assimilated to the feature specification [$\pm$ back] of the preceding harmonic vowel. The harmony process is exclusively progressive in both labial and palatal harmony systems and is also root-controlled.

Tongue root harmony, the third type of harmony, is found mainly in African languages. This harmony type has generated the most controversy with regards to the phonetic process that underlies it. Different features have been used to describe the vowels, 'covered/uncovered', (Chomsky & Halle, 1968); 'tense/lax' (Chomsky & Halle, 1968); 'advanced tongue root' (Ladefoged, 1964; Stewart, 1967); 'expanded' (Lindau, 1975). Consequently, it has been referred to in the literature as, Horizontal Harmony (Aoki, 1968, following Jakobson (1942); Relative Tongue Height Harmony (Berry, 1957; Boadi, 1963); Cross Height Vowel Harmony (Stewart, 1971); and Advanced Tongue Root Harmony (Stewart, 1967). In some languages this type of harmony is word root-controlled (for example, Akan) while others exhibit the "dominant/recessive" distinction (for example, Lango). As stated earlier, the feature [ATR], advanced tongue root, refers to the position that the tongue root assumes during the articulation of vowels. Vowels labeled [-ATR] have the tongue root retracted and those with [+ATR] have the tongue root unretracted. Subsequent sections of this chapter give a detailed discussion of tongue root harmony as it occurs in Akan.

AKAN VOWEL HARMONY

Akan may be considered a canonical example of a language exhibiting the "advanced tongue root" [ATR] harmony. Akan has 10 phonetic vowels (Lindau, 1975) that can be divided into two sets, [+ATR] and [-ATR]. Below is an inventory of Akan vowel phones in the different harmony classes. /æ/ does not occur in some dialects of the language.

[+ATR]	i	e	æ	o	u
[-ATR]	ɪ	ɛ	a	ɔ	ʊ

[+ATR] vowels have been described as having a relatively high tongue position (Berry, 1957; Boadi, 1963). Their points of maximum constriction are little more forward position in the mouth and are sometimes said to have a breathy and hollow quality (Berry,1952; Dolphyne,1988). [-ATR] vowels, on the other hand have a relatively lower tongue position and are articulated further back in the mouth. They are sometimes said to have creaky quality (Berry, 1952). Many researchers prior to Ladefoged (1964) and Stewart (1967), saw relative tongue height as the articulatory basis of harmony in the language and thus discussed the vowels as being either raised (that is high tongue position - [+ATR]) or unraised (that is, low tongue position - [-ATR])

The following is a brief outline of the operation of vowel harmony in the Asante dialect of Akan. This outline represents a very much simplified description of the phonology of Akan vowel harmony:

a) Vowel harmony is generally a property of the word in Akan.

b) Harmony across morpheme, and sometimes word, boundaries is a regressive process where, the (-) value of the harmonic feature is assimilated to the (+) value:

$$\begin{bmatrix}+\text{syll}\\-\text{cons}\end{bmatrix} \longrightarrow [+\text{ATR}] \quad \underline{\qquad\qquad} \quad +(C_o)\begin{bmatrix}+\text{syll}\\-\text{cons}\\+\text{ATR}\end{bmatrix}$$

	[ɔ+ bɛ+ tu]	[o+ be+ tu][3]
[± ATR]	- - -	+ + +
	"he+will+throw"	"he + will + dig"

c) The [+ATR] vowel /æ/ occurs only before the high vowels /i, u/ and occasionally before /o/. It is the only [+ATR] vowel that does not trigger assimilation of the [-ATR] prefix vowel that immediately precedes it:

	[ɔ + pætu]	[wɔ + bɛ + kæri]
[± ATR]	- + +	- - + +
	"he +pretends"	"they + will + weigh"

d) As stated earlier, the vowel /a/ is a neutral vowel and occurs with both harmony classes. Occasionally [-ATR] vowel /ɛ/ also act as a neutral vowel:

[3] Harmony is controlled by the root morpheme, underlined above

[sika] "money" [ohia]" poverty"

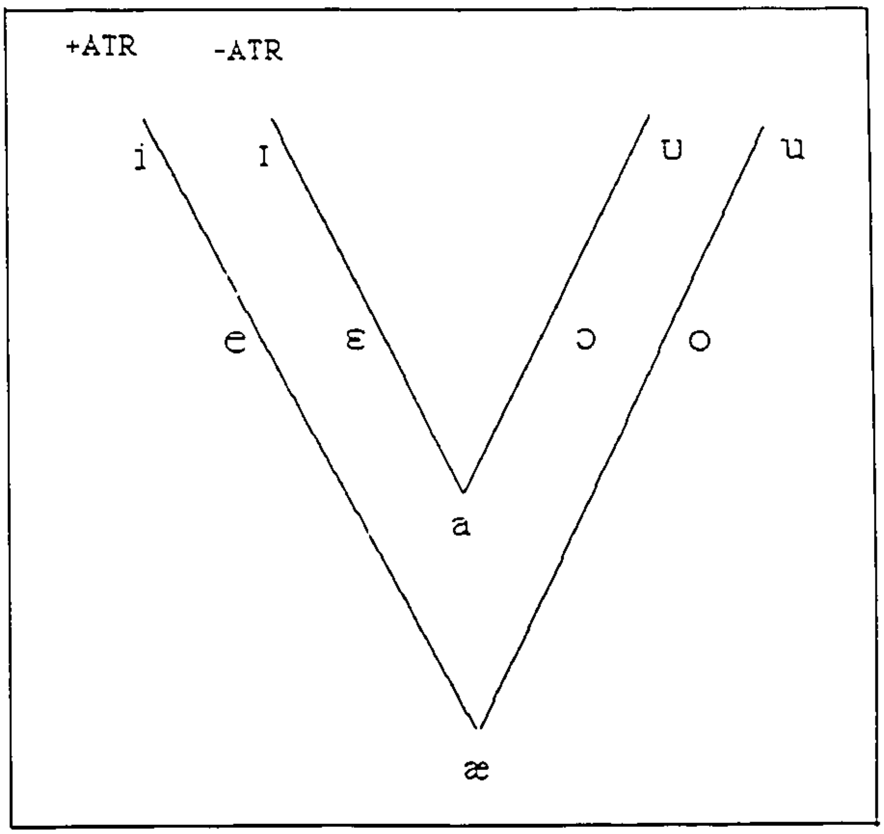
[± ATR] + - + + -

[ɲisɛ̀] "be pregnant"

[± ATR] + -

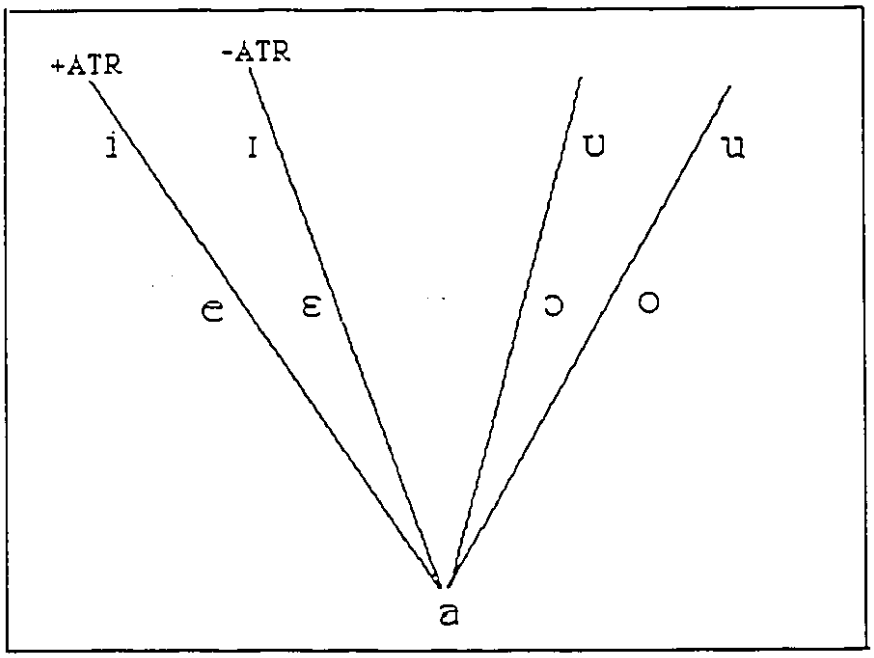
THE STATUS OF /æ/

FIGURE 2.1 : 5 BY 5 VOWEL HARMONY SYSTEM



Though it has been reported in some African languages e.g. Abe, (Stewart,1971), Kasem, Sisala, Mianka (Bendor-Samuel, 1971), a maximal system of 5 + 5 vowels (i.e., a system in which there is a one to one correspondence between [+ATR] vowel and [-ATR] vowels) is relatively rare (Figure 2.1). In these languages, the low vowel /æ/ is considered a phoneme with the same phonological status as all the other phonemes. In many other languages the low vowel [æ] has apparently merged with other low or mid vowels, resulting in a system of 4 + 4 + /a/ (Lindau, 1975), (Figure 2.2). As was indicated earlier, in some Akan dialects ,e.g., Fante, /æ/ has merged with /e/ (Dolphyne, 1988). /a/ thus acts as a neutral vowel in these dialects and may be attached to any of the harmony groups.

FIGURE 2.2 : 4 BY 4 VOWEL HARMONY SYSTEM



The status of [æ] in Akan, has been discussed considerably in the literature (Berry,1957; Schachter,1962; Schachter & Fromkin,1968; Clements,1981; Dolphyne,1988). Giving contrasts such as [ntɛm] "hurry"/ [ntæm] "between"/ [ntam] "oath" and [nsɛm] "words" / [nɪsæm] "in his hands" / [esam] "flour", one could easily conclude, using a Bloomfieldian analysis, that [ɛ, æ, a] are separate phonemes. This, however, is not necessarily the case. The words containing [æ] end with a reduced [mu] "inside" morpheme. The reduction has thus "phonologised" the contrast between [ɛ], [a] and [æ] in these words.

Considering the extremely limited number of such contrasts, the fact that [æ] occurs only before the high vowels [i, u] and very rarely before [o] as in [ægoo], "knock, knock"; [æko], "parrot", and also that native speakers of Akan also appear to have some difficulty distinguishing [æ] from [a], (Stewart, 1967), it is reasonable for one to ask if [æ] is not derived from an allophonic rule specific to /a/. Dolphyne (1988) believes this to be the case. She assigns Akan the phonemic inventory in Figure 2.2.

PHONETIC BASIS OF VOWEL HARMONY

As has already been stated, the features used to describe vowel harmony, and for that matter vowels, have generally been assumed to be articulatorily-based. Before these features can be accepted as valid, one needs to answer certain important questions: Do the features relate to any of the actual physical parameters that control the speech mechanism? What acoustic or auditory consequences can one expect from the "articulatory movements" that define these features?

Studies over the years have shown that the correlates of all features are not exclusively articulatory, as claimed by Chomsky and Halle, (1968), or acoustic, as proposed by Jakobson, Fant, and Halle (1952). Some features appear to have straightforward articulatory correlates, some, acoustic, some auditory (perceived quality), while others have various combinations of these correlates (Lindau,1975).

Traditionally, linguists have classified vowels along a vertical scale, that is, vowel height (high, mid, low) and a horizontal scale, that is, advancement (front, central, back). Evidence from articulatory studies (Ladefoged, 1964,1975; Lindau et al,1975) shows that vowel height (as shown on the Jonesian quadrilateral) does not correspond to the highest points of the tongue during speech production. When plotted on a formant chart, vowels show a vertical relation that is similar to what is observed on the traditional vowel triangle. There is a strong correlation between the variations in F1 and the traditional vowel height dimension. The F1 variation seems to better represent how vowels are perceived. (Ladefoged, 1964,1971,1975; Nearey, 1980).

The feature [back] does not accurately correspond to the highest point of the tongue along a horizontal scale (Lindau, 1975). The acoustic dimension provides better correlates for this feature. Plotting the vowels on a scale of F1 by F2-F1 (where F2-F1 = the difference between F2 and F1) provides a better and more accurate picture of "horizontal relation" between the vowels and they show a relationship to each other that is close to what one finds on the traditional quadrilateral.

It is apparent then that variations in the phonological features, height and advancement, are not solely articulatorily based but also acoustic. Turning to the vowel harmony feature as it occurs in Akan, what is the "physical interpretation" (following Nearey, 1980) of the feature that separates the vowel harmony classes? Prior to Ladefoged (1964) and Stewart (1967) there were two competing views about the underlying phonological feature of Akan vowel harmony. One was that the difference between harmony sets was that of relative tongue position: [+ATR] vowels had a high tongue position while [-ATR] vowels had a low tongue position. The other view was that the two sets differed in tenseness: [+ATR] vowels were considered as tense while [-ATR] vowels were considered lax.

Stewart (1967) contests the adequacy of the tongue-raising hypothesis on phonological grounds, namely, the results one gets from [-ATR]-to-[+ATR] assimilation. He contends that although assimilation involves the assimilated sound becoming more like the sound that triggers the assimilation, one finds that in Akan when the high [-ATR] vowels /ɪ,ʊ/ are assimilated to the non-high [+ATR] vowels /e,o/ the results are a high [+ATR] /i, u/. The problem here, according to Stewart, is that there is a change in tongue height and assimilation not only fails to eliminate the difference in tongue height but actually increases it.

One finds that in the literature, the feature "tense/lax" means different things to different investigators (Jakobson & Halle, 1962; Chomsky & Halle, 1968). This being the case, what constitutes a tense/lax distinction in European languages may not necessarily hold for Akan or other African languages. According to Jakobson & Halle (1962), lax vowels in European languages are nearer the middle of the vowel quadrilateral than the corresponding tense vowels, but Stewart (1967) and Lindau (1975) provide evidence from African languages suggesting that the "so-called" lax (-ATR) vowels generally tend to be further away from the middle of the quadrilateral than the "so-called" tense (+ATR) vowels.

As a result of arguments such as the above there was a need for further investigation into other factors, particularly, the articulatory movements that could possibly account for this type of vowel harmony. Tongue root advancment was proposed as the primary articulatory difference between the two sets of vowels (Ladefoged, 1964; Stewart, 1967; Painter, 1973; Lindau, 1975, 1979).

ADVANCE TONGUE ROOT [ATR] FEATURE

Stewart (1967), based on x-ray data, noted that [+ATR] vowels apart from having a high tongue position, are also produced with the bundle of muscle above and in front of the glottis being pushed markedly downward resulting in chin lowering. He concludes:

> This was an intriguing combination; it means that the mass of tissue between the upper surface of the tongue and the lower surface of the chin expanded both upwards and downwards for the raised vowels. Only one thing, I thought, could account for it: the pushing forward of the root of the tongue as described by Pike, 1947. (Stewart,1967:197)

Cine-radiographic data from Igbo (Ladefoged,1964) and Akan (Lindau,1975; Painter,1973) show the tongue root to be retracted for the [-ATR] vowels and less retracted for the [+ATR] vowels. Commenting on the Igbo data, Ladefoged (1964) (as quoted in Stewart,1967) notes:

> There is little difference between i and ɪ and o from the point of view of the classic description in terms of the highest point of the tongue. Nor, in these cases, is it any more profitable to use the more recent specification in terms of the cross-sectional area and place of maximum constriction of the vocal tract as suggested by Stevens and House (1955). The most striking difference between the vowels in the two sets is that in each case the body of the tongue *[which includes the root of the tongue: RAP]* is more retracted for the vowel of set 2 *(-ATR)*. (Stewart, 1967:198)

There is also found to be a systematic variation of the larynx (Lindau,1975,1979,1987; Jackson, 1988). The larynx is lowered for the [+ATR] vowel and raised for the [-ATR] vowels. The overall effect of variation in the positions of the tongue root and larynx is having the pharyngeal cavity expanded for the [+ATR] vowels but constricted for the [-ATR] vowels. What kind of acoustical consequence would one expect from this variation of the pharyngeal cavity? Various conclusions have been reported in the literature. Halle & Stevens (1969) report the lowering of F1 frequency as the most consistent and clearest acoustic consequence of the widening of the vocal tract in the area of the tongue root. This view is also shared by Lindau (1975,1979). She reports that in Akan, with pairs of vowels that differ only in ATR value, F1 frequency is considerably lower for corresponding pairs of [+ATR] vowels than for [-ATR] vowels. For example for the front high vowels /ɪ/ and /i/, she suggests that the difference is never smaller than 100 Hz. Since the F1 of front vowels is affected by tongue height position and that of back vowels is affected by the point of maximal constriction, it would be difficult to determine the tongue root position of an unknown vowel just based on the F1 value. Also given that the effect of changing the size of the pharyngeal cavity is similar to the effect one gets by lowering the tongue body at the front part of the mouth, it would be difficult to attribute convincingly the differences in F1 frequencies of cross-height vowel pairs of differing heights to their ATR values. This is because for these vowels, the effects of tongue root position and tongue height/point of maximal constriction cancel each other (Hess, 1992).

In a study of the effects of larynx lowering on Swedish vowels, Lindblom & Sundberg (1971), on the other hand, report an overall lowering of all formant frequencies. They suggest F2 to be the most sensitive formant to any variations of the pharyngeal cavity caused by lowering and raising of the larynx. For most vowels, the effect on F1 is only about 5% - 6%. The effect on F2 is quite large, particularly for front vowels. F3 on the other hand appears to show very little or no variation. They attribute this behavior of F3 to the "front-cavity affiliation of this formant". F4 on the average, drops by about 5%. The lowered larynx results in a reduction of the frequency distance between F3 and F4. This situation is similar to what Sundberg (1970) reports for sung vowels articulated with a lowered larynx.

Because of these differing conclusions, researchers continue to investigate the acoustic correlates of the ATR feature. Hess (1987,1992) investigates this problem. She attempts to find acoustic correlates that would distinguish the feature ATR (Advanced Tongue Root) as it occurs in Akan vowel harmony.

ACOUSTIC ANALYSIS OF THE FEATURE [ATR]

Hess (1987,1992) examines data from the Kwahu dialect of Akan. Kwahu has 9 phonemic vowels plus the allophone [æ]. Hess looks at five acoustic measures: formant frequency, formant bandwidth, duration, fundamental frequency, and also the amplitude of the first three harmonics, to see if any can be used to distinguish between advanced and unadvanced vowels. (See Appendix II for the word list used by Hess.)

Formant Frequencies

Measuring the frequencies of the first four formants from a wide band spectrograph, Hess concluded that the formant values did not reveal any significant overall differences between [-ATR] and [+ATR] vowels. However, she reports "there are F1 differences between two members of any vowel harmony pair, e.g., /i/ vs /ɪ/, but the high [-ATR] /ɪ,ʊ/ vowels have very similar formant values to the mid [+ATR] /e,o/ vowels, respectively" (1992:479), a finding similar to what Lindau (1979) observes in the Asante and Akyem dialects. Hess notes that on an F1 by F2 plot the formant values for /ɪ/ and /e/ as well as for /ʊ/ and /o/ overlap in space. Appendix III gives the means of the first four formants of all the vowels she recorded.

Vowel Duration and VOT

Hess also finds some considerable differences between the [+ATR] and [-ATR] vowels with regard to vowel duration and the VOT of bilabial plosives immediately preceding the vowel. The [-ATR] vowels tend to be associated with longer VOT and shorter vowel duration, while the [+ATR] vowels go with shorter VOT but longer vowel duration. However, because the ranges for the different vowels overlap considerably, for example, vowel duration for /i/ 100-140 versus /ɪ/ 98-112, she suggests that it would be impossible for one to rely on this measure to determine the tongue root position of an unknown vowel. Furthermore, Hess reports that an analysis of variance of /ɪ/ and /e/ reveal their duration difference to be less than the 0.01 significance level, ($F(13,12) = 4.736$, $p = 0.0392$). We will have reason to question this conclusion in Chapter Three.

Fundamental Frequency

Hess suggests that fundamental frequency (pitch) is not a good distinguishing factor. There appears to be very little variation among vowels of the different harmony sets.

Spectral Balance

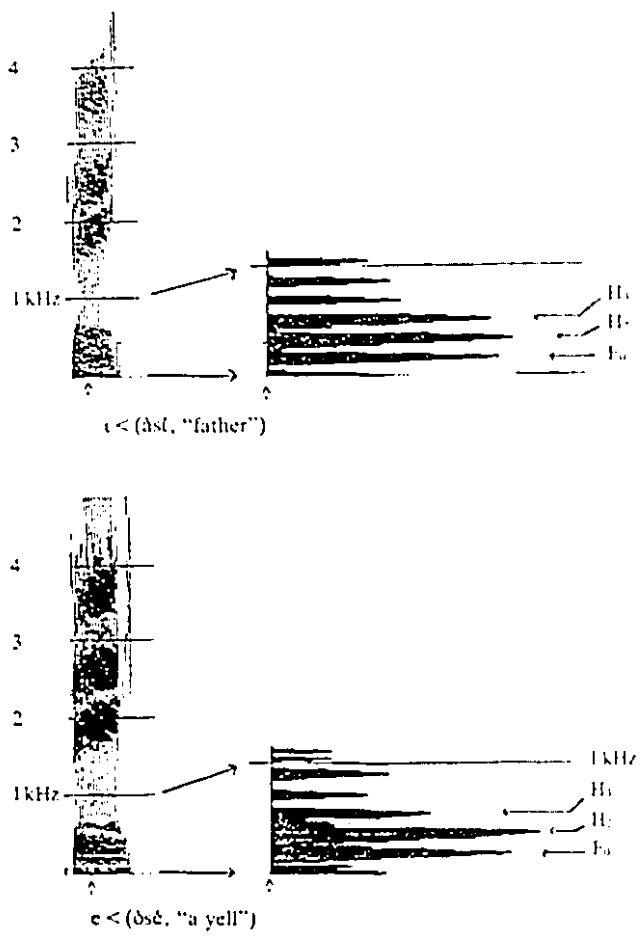
To explain the 'observation' that [+ATR] vowels have a perceptible breathy quality, Halle & Stevens (1969) hypothesize that [+ATR] vowels have a particular phonation type that has a broad glottal pulse and consequently contains more energy at lower frequencies. This being the case one would expect [-ATR] vowels to have more high-frequency energy in the F2 and F3 regions than [+ATR] vowels. Applying this reasoning to the Kwahu data, Hess measures the difference in peak amplitude between F1 and F2 for the different vowels and concludes that there are no consistent differences between the harmony sets. Having failed to find any correlation between the amplitudes of F1 and F2, Hess examines another measure of spectral balance proposed by Ladefoged et al. (1988), H_2 - F0, in the Kwahu data.

Ladefoged et al. attribute the "so-called" breathy quality of [+ATR] vowels to the difference in amplitude between the 2nd harmonic (H_2) and fundamental frequency (F0), that is, H_2 - F0. Based on data from Jalapa Mazatec, they suggest that sounds articulated with a breathy voice would have a decreased amplitude of the second harmonic in relation to the F0. Here again Hess finds no such correlation between the H_2 - F0 measure and the ATR feature value. She concludes that the difference in amplitude values between the first and second formants, and also between the first and second harmonics, did not reveal any consistent difference between the two harmony sets.

Formant Bandwidth

Hess (1987) notes what appears to be an interesting phenomenon, with regard to the formant bandwidth. Measuring the bandwidths of the first three formants at -6dB from the peak amplitude of each formant, she observes "the bandwidth of the first formant proved to be the easiest to measure and moreover showed consistent difference between high and mid vowels which belong to different harmony sets" (1987:64). Overall the bandwidths increase as F1 increases. There also appeared to be a correlation between the width of the bandwidth and the relative strength of the third harmonic, H_3. All the [+ATR] vowels have a narrower first formant bandwidth and a weak third harmonic (H3) and the [-ATR] vowels have a broader F1 bandwidth and stronger H3. Figure 2.3 illustrates this. It shows a power spectra and wide band spectrogram for /ɩ/ and /e/. There is a consistent bandwith difference between the overlapping vowels /ɩ/ and /e/. Because these vowels have similar F1 frequencies, Hess (1987) suggests that the difference in F1 bandwidth could be a result of their tongue root positions.

FIGURE 2.3: Wide band spectrogram and power spectra for one token of /ɩ/ and one token of /e/ (from Hess, 1987)



Given that the studies of Indo-European languages reveal that the bandwidths of the formants do not markedly distinguish different vowels (Fant,1960a; Flanagan,1972), and formant amplitude and bandwidth are secondary to the accurate perception of vowel quality (Minifie et al.,1973), can one safely attribute this difference in bandwidth consistently to the difference in tongue root position or is it a result of other phonetic mechanisms yet to be factored out?

The 1987 study simply correlates bandwidth differences to the relative strength of the 3rd harmonic. A later study (Hess, 1992) of the nature of assimilation between the harmony sets reveals that the third harmonic is not a good predictor of bandwidth differences. This led Hess to further investigate bandwidth differences without correlating them to harmonic differences. In the 1992 study she measured the bandwidth values at various points of the vowel, beginning 30ms into the vowel, and then she calculated the average bandwidth and frequency value of each formant using an LPC analysis to solve for the roots of the resulting z-polynomials. The bandwidth values that resulted corresponded to the bandwidth values at -3.13 dB from the peak amplitude. Here again she found that [+ATR] vowels had narrower bandwidths than [-ATR] vowels. The F1 bandwidths of the [-ATR] were wider than those of [+ATR]s:

> "The /ɪ,e/ and /ʊ,o/ pairs are separated more in the vertical dimension (F1 bandwidth) than in the horizontal dimension (F1 frequency). For /ɪ,e/, there is an 11% difference in F1 frequency, but a 33% difference in F1 bandwidth. For /ʊ,o/ the difference in F1 frequency is similar to /ɪ,e/ at 10%, but F1 bandwidth difference are even more dramatic at 66%" (Hess,1992:485).

A one-way ANOVA shows that the differences in both F1 frequency ($F(13,11) = 27.533$, $p=0.001$) and F1 bandwidth ($F(13,11) = 17.938$, $p=0.0003$) are highly significant. However, the correlation between formant frequency and formant bandwidth is rather mild. This appears to reinforce Hess's (1987) suggestion that differences in F1 location do not in themselves affect bandwidth for these pairs. Having established the bandwidth as the most likely reliable measure that distinguishes vowels of the different harmony sets, Hess examines the nature of vowel assimilation in Kwahu.

VOWEL ASSIMILATION

Two claims have been put forward concerning assimilation between the harmony sets across morpheme and word boundaries. One claim is that assimilation is partial, that is, it involves a change in tongue body position, namely the center of the tongue, alone. This position is held by Clements (1981). According to him, a more "general and extensive vowel-raising rule" applies to all [-ATR] vowels when the first syllable of the following word begins with a [+high, +ATR] vowel. This implies a kind of lower level assimilation that does not affect the phonological status of the vowels. According to Clements, when this raising rule is applied, the vowels are affected according to their "phonetic height":

a) raised high [-ATR] vowels merge completely with their corresponding [+ATR]:

$$\begin{Bmatrix} \text{I} \\ \text{U} \end{Bmatrix} \longrightarrow \begin{Bmatrix} \text{i} \\ \text{u} \end{Bmatrix} \Big/ \underline{\qquad} \; \# \begin{bmatrix} +\text{high} \\ +\text{ATR} \end{bmatrix}$$

b) raised mid [-ATR] vowels become acoustically intermediate between the [-ATR] and [+ATR] values:

$$\begin{Bmatrix} \varepsilon \\ \text{ɔ} \end{Bmatrix} \longrightarrow \begin{Bmatrix} \text{E} \\ \Theta \end{Bmatrix} \Big/ \underline{\qquad} \; \# \begin{bmatrix} +\text{high} \\ +\text{ATR} \end{bmatrix}$$

where $\text{e} > \text{E} > \varepsilon$

$\text{o} > \Theta > \text{ɔ}$ on the ATR scale

c) the low vowel /a/ remains just raised at a word boundary i.e., still maintaining the [-ATR] value. If the boundary is deleted or changed, /a/ becomes both fronted and raised [æ]:

R1

$$[a] \longrightarrow [A] \; / \; \underline{\quad\quad} \; \# \begin{bmatrix} +\text{high} \\ +\text{ATR} \end{bmatrix}$$

where /A/ = raised /a/

R2

$$[a] \longrightarrow [æ] \; / \; \underline{\quad\quad} \; \begin{Bmatrix} \$ \\ + \\ \emptyset \end{Bmatrix} \begin{bmatrix} +\text{high} \\ -\text{ATR} \end{bmatrix}$$

Clements further claims that vowel raising "is not local to the syllable immediately preceding the conditioning syllable, but influences the articulation of preceding syllables as well causing them to acquire increasingly raised variants...." (1981: 157).

The second proposition is put forward by Dolphyne (1987). According to her, all vowels except the [-ATR] high vowels, harmonize across word boundaries and word-internally; "the unadvanced vowel immediately preceding the advanced vowel is replaced by a corresponding advanced vowel" (1987:23), thus, [ɔkɔ] "he goes" + [fie] "home"= [ɔko fie] "he goes home" "

Under these conditions, assimilation is complete, that is, it would involve not only a change in tongue body but also a change in tongue root position. Across word boundaries, [-ATR] high vowels [ɪ] and [ʊ] are not fully assimilated to the [+ATR] vowels [i] and [u]. They have a quality that is between [ɪ - i] and [ʊ - u].

$$\begin{Bmatrix} \text{I} \\ \text{U} \end{Bmatrix} \longrightarrow \begin{Bmatrix} \text{I*} \\ \text{U*} \end{Bmatrix} \; / \; \underline{\quad\quad} \; \# \begin{bmatrix} \text{V} \\ +\text{ATR} \end{bmatrix}$$

where /ɪ,ʊ/ < /I*,U*/ < /i,u/ on the ATR scale

Also, she suggests that the assimilation process does not extend beyond the syllable immediately preceding the conditioning vowel.

These two opposite views give rise to some questions:

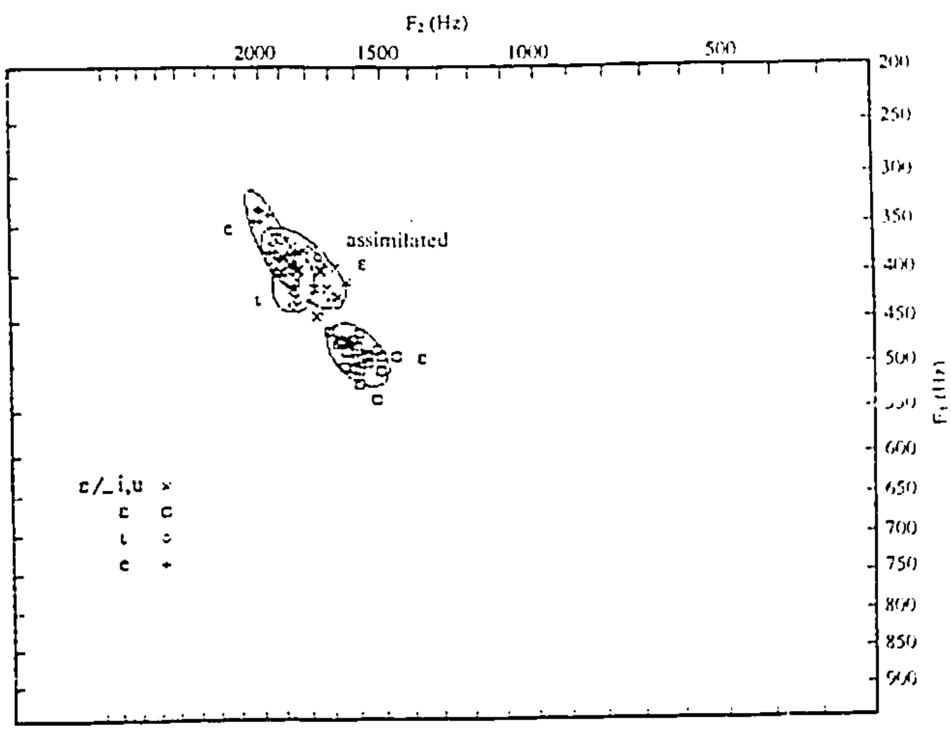
1) Could one tell, acoustically, if a [-ATR] vowel is partially assimilated or if it is fully assimilated (that is, replaced by a [+ATR] vowel)? 2) what is the extent of the assimilation process, that is, does it cover one syllable or more? 3) is assimilation gradient in nature?

If one assumes bandwidth to be the acoustic correlate of the feature [ATR], then one can hypothesize that, if assimilation is partial, then there will be a change in only formant frequency. On the other hand if it is complete, then there would be a change in both formant frequencies and formant bandwidth. Evidence presented in Chapter Three of this present study, however, indicates that bandwidth is not a reliable measure.

Using the above hypothesis as basis, Hess investigates the effects of assimilation on the mid [-ATR] /ɛ/. If assimilation is complete one would expect /ɛ/ to have similar formant values and bandwidths as the vowel /e/. If on the other hand assimilation is partial, there would be a change in only formant values and /ɛ/ would be similar to /ɪ/. /ɛ/ is placed in sentence pairs containing contexts for assimilation (/ɛ/ followed by a trigger syllable i.e. with a high [+ATR] vowels) and control context (with a following /a/).

Figure 2.4. ASSIMILATED /ɛ/ VS NON ASSIMILATED /ɛ/: F2 VS F1.

(LPC analysis) (from Hess, 1987)



Using an LPC analysis Hess computes the F1 frequencies and formant bandwidths. These measures are used because "supposedly" they most strongly correlate with [ATR] set affiliation. She finds that the "mean F1 frequency for assimilated /ɛ/ before /i, u/ is lowered to 395 Hz and is in between the F1 averages for /ɪ/ (412 Hz) and /e/ (367 Hz). The F2 average for /ɛ/ before /i,u/ (1808 Hz) is more similar to /ɪ/ (1850 Hz) than to /e/ (1943 Hz)". Plotting her results on a scatter diagram, Hess revealed that the assimilated /ɛ/ appears to overlap with both /e/ and /ɪ/ but not was not entirely the same as either one (Figure 2.4). The figure shows F1 and F2 for 14 tokens of /ɪ/ and 12 tokens of /e/ are plotted for comparison. Mean F1 frequency for assimilated /ɛ/ (26 tokens)is 395 Hz, and mean F2 frequency is 1808 Hz. Mean F1 frequency for non-assimilated /ɛ/ (24 tokens) is 488Hz and mean F2 frequency is 1596 Hz.

At a glance, the results of the frequency analysis appear to support Clements' claim that assimilated mid vowels are acoustically intermediate between mid [-ATR] vowels and high [+ATR] vowels. However, having concluded that (1) F1 frequency is affected by changes in tongue height and (2) change in bandwidth is a consistent marker of ATR, Hess looks at the bandwidth values to determine if they do support the claim. Analysis of the bandwidth measures showed a consistent difference between the /ɛ/ before /i,u/ and the /ɛ/ before /a/. /ɛ/ before /i,u/ had a narrower bandwidth (mean = 45 Hz) and was comparable to the [+ATR] vowel /e/ (mean = 53 Hz). The /ɛ/ before /a/ had a bandwidth (mean = 92) comparable [-ATR] vowel /ɪ/ (mean = 75). Her results, in this case are more consistent with Dolphyne's claim that assimilation is complete (that is, involves a change in bandwidth)

To answer the second and third questions, Hess (1987, 1992) looks at the formant values of /a/ in three successive syllables within the word /adaka/ "box". /adaka/ was followed by a trigger syllable containing a [+high, ATR] vowel. If assimilation is gradient as claimed by Clements, one would expect a difference between the formant values of the initial /a/ and final /a/ syllables. As one moves from the first syllable, there would be a gradual incremental change in the frequencies of the formants. Table 2.1 shows the formant values of /a/ in the different syllables.

Hess' results reveal that the effects of assimilation are a lowered F1 and raised F2 and F3. Also, the effects of assimilation are restricted only to the third syllable in the word, /ka/, which immediately precedes the [+high, +ATR] vowel. The results support Dolphyne's claim that assimilation is not gradient and is restricted to only one syllable.

TABLE 2.1 Formant measurements of /a/ in the different syllables (in Hz)

FRAME	SYLLABLE	F1	F2	F3
a. adakasi	a	600	1420	2120
	da	600	1450	2000
	ka	440	1560	2120
b. adakasam	a	600	1450	2130
	da	620	1380	2020
	ka	590	1400	1980
c. adakamu	a	570	1500	2090
	da	580	1400	2000
	ka	415	1380	2180
d. adakamane	a	600	1450	2210
	da	580	1400	2330
	ka	660	1290	1990
e. adakabi	a	600	1420	2070
	da	590	1450	1990
	ka	450	1850	2490
f. adakaba	a	600	1490	2090
	da	600	1400	2000
	ka	660	1280	1925

PURPOSE AND SCOPE OF STUDY

This study is an attempt to clarify the nature of the acoustic distinction between [±ATR] vowels. The study also investigates the reliability of the first formant bandwidth as a "litmus" test for [±ATR] distinction of vowels that overlap in F1 and F2 space. It replicates part of Hess' work with another dialect, Asante, and with more speakers. To date acoustic analysis of Akan vowel harmony has been conducted on data obtained from 1 or 2 speakers of a given dialect. To confirm the crediblity of B1 as an acoustic correlate of ATR, it is important that vowel tokens of several speakers be examined. This study explores the following:

1) Whether F1 bandwidth correlates with the [±ATR] value of a vowel across several speakers of the Asante dialect.

2) Whether F1 bandwidth consistently distinguishes the cross-height overlapping pair /e,ɪ/.

3) Which variables are suited for use as discriminatory criteria for separating the vowels into [±ATR] harmony classes.

Throughout the discussion, the terms "correlates" and "parameters" are used interchangeably. Also the term "physical parameters" is used to refer to all types of parameters that characterize the speech signal, for example, auditory, acoustic and articulatory.

CHAPTER THREE : ACOUSTIC STUDY OF ASANTE VOWELS

DESIGN

SUBJECTS

Data were obtained from nine male native speakers of the Asante dialect of Akan. A subject was considered a native speaker if he met the following criteria:

a) the subject must have been born in an Asante speaking area

b) spent the first twenty years of his life in that area

c) Asante must have been the language spoken to him from infancy by his primary care-givers

Being a native speaker of Akan, the investigator was able to judge whether a subject's language reflected these criteria. The subjects, ranging in age from twenty-eight to forty years, were graduate students of the University of Alberta who had resided in Canada for a minimum period of three years prior to taking part in the study. None of the subjects had any prior linguistic or phonetic training.

STIMULUS MATERIAL

A word list containing the vowels /i, ɪ, e, ɛ, æ, a, ɔ, o, ʊ, u/ was used (Table 3.1). The list consisted of some words from the list of Hess (1987) (Appendix II) and three additional words for each vowel, for a total of thirty-six words. Four of the words contained two vowels of interest. The words from Hess (1987) had a VSV structure, with the vowel of interest in word final position. Initially, it was decided that the new words to be included would have a VTV structure. This structure generated mainly nonsense words. In a pilot test it was found that subjects had difficulty reading these words. They were so conscious of how they articulated them that the words sounded unnatural. However, when they were given a list of real Akan words they appeared relaxed and very comfortable. It was decided that the stimuli for the actual recording would consist of meaningful words that the subjects were familiar with.

To reduce some of the context effects, all vowels were placed both word initially and finally (sometimes also at word medial position.) A consonantal context of a bilabial/alveolar plosive, before and/or after the vowel was maintained. The list was randomized three times and the subjects were presented with three sets of words. Overall, each subject was provided with 120 vowel tokens.

TABLE 3.1 EXPERIMENTAL STIMULI

STI[4]	V'L	T'E	GLOSS	STI	V'L	T'E	GLOSS
patu	æ	l	*pretend*	tu	u	h	*uproot*
bu	u	h	*break*	ɛto	ɛ	l	*buttocks*
ɔsa	a	h	*war*	sɛsɛ	ɛ	h	*shrimp*
ate	ɪ	h	*it is torn*	ɔpɛ	ɛ	h	*dry season*
ase	ɪ	h	*under*	ɛtɛ	ɛ	h	*glaucoma*
pepa	ɪ	l	*wipe*	asɔ	ɔ	h	*hoe*
tobi	o	l	*buy some*	bɔtɔ	ɔ	l	*sack*
otu	o	l	*he flies*	pata	a/a	l/l	*appease*
ɛpi	i	h	*it has thicken*	taku	æ	l	*5 pesewas*
bo	ʊ	h	*get drunk*	oso	o	h	*fine person*
pato	æ/o	l/h	*verandah*	abɔ	a	l	*it's broken*
ɛso	ʊ	h	*top*	ɔto	ɔ	l	*he throws*
butu	u	l	*up turn*	tabi	æ	l	*boy's name*
atɔ	ɔ	h	*it's fallen*	potɔ	ʊ	l	*mash*
ose	e	h	*a cry*	pepe	e/e	h/h	*northern*
asi	i	h	*it's happened*	etu	e	l	*it flies*
to	ʊ	h	*throw*	tɛtɛ	ɪ	l	*hide*
apiti	i/i	h	*name of a small bird*				
osu	u	h	*"Osu" name of an area in Accra*				

SUBJECTS' INSTRUCTIONS AND PROCEDURE

The vowels were recorded for each subject using the right channel of a TEAC V-437C stereo cassette recorder, connected to a Sennheiser MD 42 1N microphone.

[4] "STI" refers to stimuli, "V'L" to vowel and "T'E" to tone.

The thirty minute recording session took place in a sound treated room. To enable subjects to maintain a fairly consistent and comfortable voice level, they were taken through a five minute practice session, reading the list below, prior to recording the 108 test words.

PRACTICE LIST

	WORD	GLOSS
1.	pàpɑ́	*father*
2.	ɑdɑkɑ	*box*
3.	ɑkokɔnini	*cockerel*
4.	ɑsɔredɑn	*chapel*
5.	ɔbɔfo	*hunter*
6.	pɑ́pɑ́	*good*

Next, subjects were asked to read from the three lists of words, taking a two minute break between lists.

The recordings were next bandpass filtered through a Rockland Programmable Dual Hi/Lo Filter set at 68Hz - 7800Hz. They were then digitized at a sampling rate of 16kHz on an IBM AT computer, using the CSRE (Canadian Speech Research Environment) software. The computer was equiped with a DT2801A A/D D/A conversion board with a quantization size of 12 bits. For each vowel token, the entire word was digitized. The procedure created audio data files (ADF) for each vowel token.

The Raw Track (RTR) sub-system of the software, was used to produce a parametric description of each ADF file. The default values of the program were used. The hop duration, which determined how far the windows were advanced for successive frames, was set at 5ms.

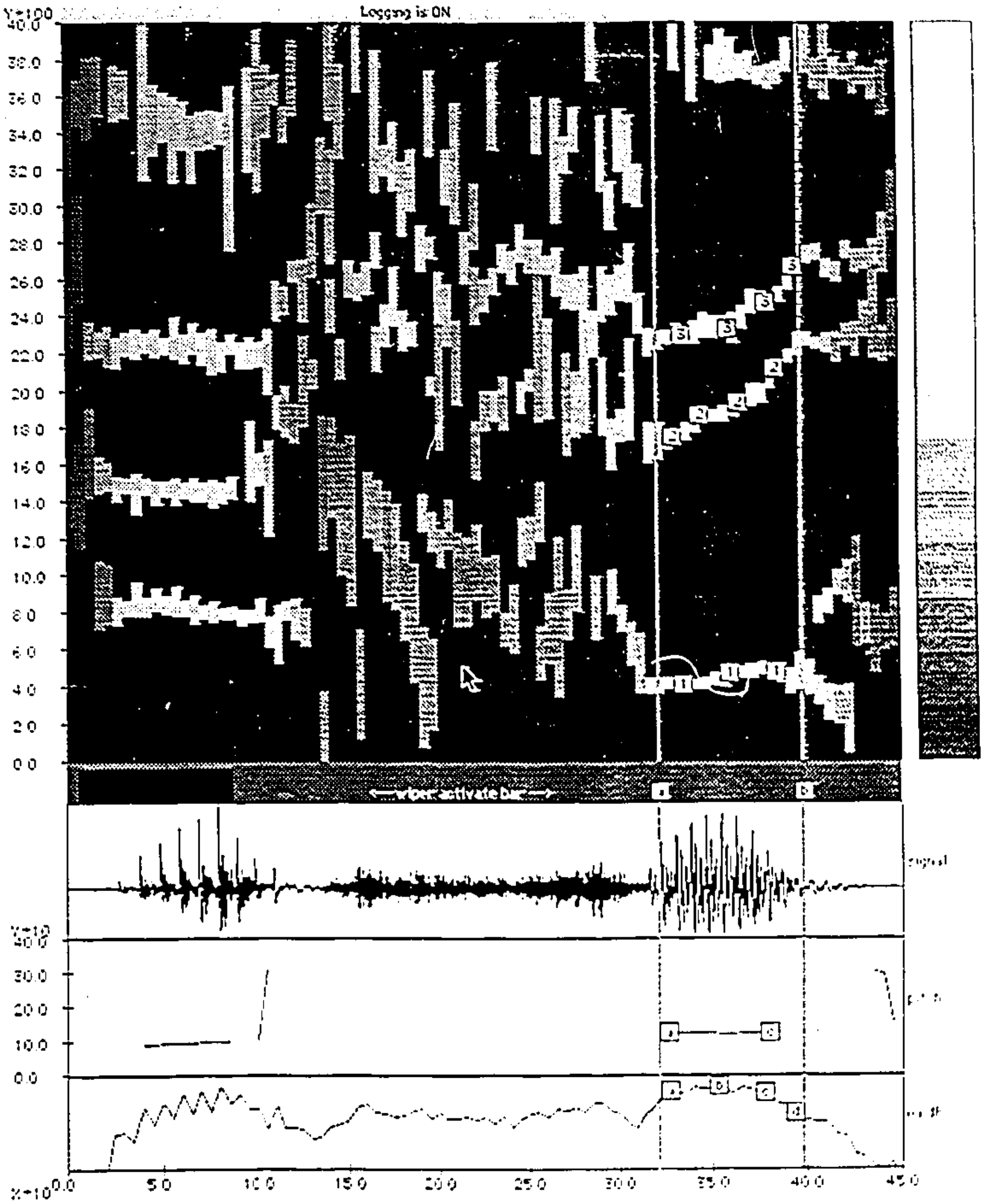
The parameters produced on output were the estimates of frequencies, bandwidths and amplitudes of potential formant peaks, the overall signal amplitude and the fundamental frequency (the overall pitch). The fundamental frequency (F0) estimates were determined by means of a cepstral analysis. The formant estimates were presented in a frequency sorted order. These estimates did not always represent the actual formants of a signal. Sometimes, "false" peaks were identified while true formants were missed. On a schematic wide-band spectrogram of the individual signals, the investigator manually marked the onset and end of the vowel segments (Figure 3.1). The investigator also placed formant frequency markers along each formant trajectory and also markers along the fundamental frequency and amplitude trajectories. Sometimes, because the formants had very low energy, they could not be captured by the program. Tokens with such "missing" formants were not used. Of the 1080 vowel tokens digitized, 76 were discarded for the following reasons: some were mispronounced by the subjects, others had missing formants, while the remaining had measurement errors, for example, F2 being labeled as F3 by the investigator. The discarded vowels did not follow any particular pattern and were not unique to any one particular subject.

Special output files, rich note files (RNF), were created for each ADF file. These contained the assigned formants, amplitudes and fundamental frequency (FO) values at the hand-selected intervals. To check the validity of the formant candidates and to find a representative value for each formant, the RNF files were run through a Skeletal Formant tracking program which aligned the formants to skeletal tracks. This program was developed by T. Nearey (University of Alberta).

An estimate of the formant frequency for a given frame of analysis (kth frame) was represented by $Tm(k)$, which was calculated over the relevant period as a linear interpolation of the frequency values specified in the RNF file. This estimate was referred to as the skeletal formant track. A dynamic programming algorithm was used to optimize the fit of the tracked formants to their skeletal estimates. The following frequency boundaries were set for the alignment of each formant: F1 = 150 -1125; F2 = 375 - 3750; F3 = 1125 - 5700. An alignment was legal if all the slotted candidates were within the above ranges and the formants were in an increasing order of frequency.

For each token of the vowel, the analysis produced on output, the median values (over the middle 50% of the vowel) of the formant frequency ($F(k)$med, where K represents the formant), the formant bandwidth ($B(k)$med), the formant amplitude ($A(k)$med), also the number of good formants (ngF(k)); proportion of good formants (pgF(k)), the inter-quartile range of the formant frequency ($F(k)$iqr), the inter-quartile range of the formant bandwidth ($B(k)$iqr) and the inter-quartile range of the formant amplitude ($A(k)$iqr).

FIGURE 3.1: SPECTROGRAM OF /ɑsɪ/



The procedure used here to extract frequency and bandwidth values differed from that employed by Hess. Hess used a root solving technique to extract the values, "bandwidths and frequencies were obtained from LPC analysis by solving for the roots of the resulting z-polynomials. Bandwidths obtained by this method correspond to the bandwidth at -3.13dB from peak amplitude." (1992:484). The method used in the CSRE software is based on the FINDPK algorithm of Markel & Gray (1976:167 - 169) Although the absolute bandwidth estimates in this present study will differ somewhat from Hess', it is not expected that relative bandwidth values will be affected when comparing vowels of the different categories. Since the median bandwidth values were used over several frames, it is likely that reliable differences of any perceptual relevance would be captured with this present technique.

STATISTICAL ANALYSIS

Two types of statistical tests were performed - a repeated measures ANCOVA implemented in a general linear model and a stepwise discriminant analysis. The motivation for these tests lies in two theoretical approaches to relating physical correlates to phonological features discussed in this thesis, namely, the one-to-one mapping approach pursued by Hess (1987, 1992) and the many-to-many mapping favored by Lindau & Ladefoged (1986). In a one-to-one mapping model, a feature is assigned a single measurable physical correlate that serves as a reliable marker for the feature across several speakers. A repeated measures ANCOVA implemented in a general linear model would enable one to determine if indeed a 'silver bullet correlate' is significant in classification of speech sounds in terms of the phonological feature. The many-to-many approach defines a phonological feature in terms of several physical correlates. To determine the nature of the relationship between the correlates and the feature, the correlates would first have to be isolated. Studies in this phonetics laboratory (e.g. Assman, 1979) provide ample evidence that discriminant analysis has adequate power to in extract such variables in speech perception studies.

GENERAL FORMANT FREQUENCY PATTERNS OF [±ATR] VOWELS

Table 3.2.1 contains the across subjects' median values of F1, F2 and F3 of all the vowels, while Table 3.2.2 gives their standard deviations.

TABLE 3.2.1 FORMANT FREQUENCY VALUES OF ASANTE VOWELS (in Hz)

VOWELS	F1	F2	F3
i	315	2069	2831
ɪ	395	1934	2549
e	401	1949	2544
ɛ	592	1780	2456
æ	563	1597	2341
a	771	1358	2276
o	387	943	2319
ɔ	609	1010	2193
u	318	1037	2261
ʊ	444	922	2330

TABLE 3.2.2: STANDARD DEVIATION OF F1, F2, AND F3 VALUES (in Hz)

VOWELS	F1	F2	F3
i	46.1	98.2	129.5
ɪ	34.7	125.3	317.8
e	40.8	109.5	133.9
ɛ	45.0	100.2	150.2
æ	59.2	139.5	212.3
a	72.3	104.5	422.6
o	43.5	108.8	200.6
ɔ	28.3	63.4	250.6
u	44.5	204.7	154.8
ʊ	43.9	121.9	211.2

There is a difference in F1 frequency in the vowel harmony pairs. The [+ATR] vowels have lower F1s. This is consistent with the earlier findings of Halle & Stevens (1969) and Lindau (1975,1979). There are also F2 differences which are, however, not consistent with the claims of Lindblom & Sundberg (1971) with regard to the downward movement of the larynx. Except for /o/, the [+ATR] vowels have higher F2s.

REPEATED MEASURES ANCOVA

The analysis looked at significance of first formant bandwidth and duration in the separation of the [±ATR] vowels and the overlapping front vowels, /ɪ,e/. The data for the ANCOVA were restricted to Hess's vowel tokens. A mixed-factors design was employed, with "subjects" (sjC) being treated as a random factor and F1, B1, duration (dur) and [±ATR] vowel distinction (atr) as the fixed covariates. To control for the effects of the covariates, a sequential sum of squares test was used. With this test, the effects of factors were removed in a sequential manner. The level of significance was set at 0.05 .

<u>B1 Analysis For All ATR Pairs</u>

The significance of B1 was of interest because according to Hess (1992) it is a reliable "litmus" test for the [±ATR] distinction, particularly for the vowels /ɪ,e/ which are supposed to overlap in F1 formant space. The outcome of this analysis is shown in Table 3.3.1. The main effect terms were atr and sjC, and the interaction effect term was subject*atr. Following Hess (1992), without controlling for the effects of other covariates, F1, dur, and subjects, [±ATR] vowels did not show a significant difference in B1, ($F(1,185) = 0.24547$, $p = 0.6336$). The interaction effect was however significant ($F(8,185) = 4.7367$, $p < 0.0001$). This was an indication that some subjects used B1 in the separation of their [±ATR] vowels.

TABLE 3.3.1: ANALYSIS OF B1 WITHOUT CONTROLLED COVARIATES

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F - RATIO	PROB.
Const	1	969273	969273	628.99	≤ 0.0001
sjC	8	12328.0	1541.00	2.5916	0.0105
atr	1	691.362	691.362	**0.2455**	**0.6336**
sjC*atr	8	22531.8	2816.47	**4.7367**	**≤ 0.0001**
Error	185	110002	594.607		
Total	202	145553			

When all the covariate and subject effects were controlled for, the two harmony classes still did not show a significant difference in B1 (Table 3.3.2) $(F(1,183) = 0.0311, p = 0.8644)$. The interaction effect on the other hand was significant $(F(8,183) = 4.7458, p \leq 0.0001)$.

TABLE 3.3.2: ANALYSIS OF B1 WITH CONTROLLED COVARIATES

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F - RATIO	PROB.
Const	1	969273	969273	628.99	≤ 0.0001
sjC	8	12328.0	1541.00	2.6061	0.0101
F1	1	1564.08	1564.08	2.6452	0.1056
dur	1	916.408	916.408	1.5498	0.2148
atr	1	87.3323	87.3323	**0.0311**	**0.8644**
sjC*atr	8	22449.7	2806.21	**4.7458**	**≤ 0.0001**
Error	183	108208	591.300		
Total	202	145553			

Subject JO and to a lesser extent subject SF displayed a strong correlation between ATR and B1 (see correlation matrix, Table 3.4), 0.706 for JO and 0.509 for SF. However, when, F1 was controlled for, the [±ATR] vowels of SF did not show a significant difference in B1, $(F(1,24)= 1.741, p= 0.1995)$. Subject JO on the other hand still maintained the B1 distinction $(F(1,24)= 7.875, p= 0.0098)$.

TABLE 3.4: CORRELATION BETWEEN
ATR AND F1/B1/F2

SUB		F1	B1	F2
AAS	A	*0.550*	0.287	-0.181
FB		*0.549*	0.375	-0.134
GA		*0.618*	0.078	-0.062
IA	T	*0.718*	0.061	-0.196
PK		*0.653*	0.039	-0.272
JO		***0.706***	**0.706**	-0.234
NA	R	*0.781*	0.138	-0.442
SF		***0.645***	**0.509**	-0.216
YO		*0.595*	0.077	-0.295

B1 Analysis For The Overlapping Vowels /ɪ,e/

According to Hess (1992), the overlapping vowels, /ɪ,e/ displayed a significant difference in F1 bandwidth. This however was not the case in the present study. The difference in B1 for the vowels was not significant ($F(1,30) = 0.5238$, $p = 0.4898$). This situation was consistent across subjects (reflected in the interaction effect, ($F(8,30) = 0.95951$, $p = 0.4850$). Contrary to Hess's conclusions, even the subjects that generally showed a B1 distinction of the [±ATR] did not show a significanct difference B1 difference in the /ɪ,e/ distinction.

From the preceding analysis, it is apparent that the first formant bandwidth is not a reliable distinguishing criteria for the ATR feature across subjects.

Duration Analysis For All ATR Pairs

The second analysis focused on duration. Although Hess (1992) reports a non-significant duration difference between the [±ATR] vowels at .01 significance level, (F(13,12) = 4.736, p = 0.0392), at the .05 significance level her [±ATR] vowels differed significantly in duration. Moreover, to find a significant difference at a 0.01 level in a sample size of n = 12 (that she used), the difference would have to be very big. To this end, it was determined that duration was a good candidate for analysis with more data.

The median duration values of the vowel pairs (Appendix IV) demonstrated [±ATR] difference that was in line with the findings of Hess (1992). Except for the /e, ɛ/ pair, the [-ATR] vowels had shorter vowel duration while their [+ATR] counterparts had longer vowel duration. In this present study, this difference was significant when all covariates, particularly F1, were controlled for (F(1,183) = 1.8759, p = 0.0107) (Table 3.5.1).

TABLE 3.5.1: ANALYSIS OF DURATION WITH CONTROLLED COVARIATES

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F - RATIO	PROB.
Const	1	2720906	2720906		
sjC	8	79309.6	9913.70	22.201	≤0.0001
F1	1	4442.93	4442.93	9.9496	0.0019
B1	1	684.068	684.068	1.5319	0.2174
atr	1	9177.77	9177.77	10.956	0.0107
sjC*atr	8	6701.37	837.672	1.8759	0.0662
Error	183	6701.37	446.544		
Total	202	81717.6			

On the other hand, when these covariate effects were not controlled, differences in duration were not significant for the main effect term, atr, (F(1,185) = 1.5529, p = 0.1418) (Table 3.5.2).

TABLE 3.5.2: ANALYSIS OF DURATION WITHOUT CONTROLLED COVARIATES

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F - RATIO	PROB.
Const	1	2720906	2720906	274.46	≤ 0.0001
sjC	8	79309.6	9913.70	19.203	≤ 0.0001
atr	1	800.155	800.155	0.9981	0.3470
sjC*atr	8	6413.61	801.701	1.5529	0.1418
Error	185				
Total	202				

The situation in Table 3.5.1 is to be expected given the symbiotic relationship between duration and F1. In Table 3.5.2, F1 acts as a suppressor variable to duration. The significance of duration is consistent across subjects. This is reflected in the non-significant values of the interaction effect, sjC*atr, in both tables ($F(8,183) = 1.8759$, $p = 0.0662$) in the controlled context and ($F(8,185) = 1.5529$, $p = 0.1418$) in the uncontrolled context.

RELATIVE DISCRIMINABILITY OF VOWELS

Rather than concentrate on duration or any other single property as an invariant marker of [±ATR], it was decided to conduct an exploratory analysis of distinctiveness of the vowels in Akan on a whole. The approach that follows is generally more suited for explaining hypotheses that included a relatively "relaxed" realation between physical properties and distinctive features such as that of Lindau & Ladefoged (1986).

The Stepwise Discriminant Analysis program of the BMDP statistical software was used to determine the "relative discriminability" (following Assman, 1979) of the ten vowel categories in terms of eleven spectral variables. These variables were the median frequency, bandwidth and amplitude of the first, second and third formants (F1, F2, F3, B1, B2, B3, A1, A2, A3), the duration (dur) and overall amplitude (A0).

The Stepwise discriminant analysis was performed in two ways. Since the BMDP software was not capable of handling the present number of data points, a random 80% was used for both discriminant analyses. The first analysis involved the use of the default forward stepping criteria. At each step, the variable with highest F statistic was automatically entered into the analysis. At step 0 the F statistic for each variable was computed from a one-way ANOVA. For the subsequent steps, the F statistics were computed from a one-way analysis of covariance where the covariates were the previously entered variable(s). At each stage this procedure allowed one to select an additional variable that provided the best statistical separation of vowels given the previously entered variables. At each stage of the analysis, a linear combination of the variables known as a classification function (CF) can be used to automatically classify the vowels. The function could also be used to predict the category of an unknown vowel. It must be noted that, Stepwise analysis does not necessarily lead to an optimal subset of vowels.

The second analysis involved a complete ordering of the variables and a specification of the number of steps that occurred in a given analysis. This procedure allowed for the control of the order in which the variables occurred in a theory-guided way. It also allowed for the effects of the individual variables to be isolated.

Two measures of relative discriminability were used, the relative separation between the vowels and the percentage of correct classification (C.C.) for each vowel category and the entire set of vowels. The relative distance or separation between the means of any two vowel categories was represented in the form of an F matrix. The matrix contained the F ratios that had been computed from the Mahalonobis D2 statistic. The larger the value, the greater the separation of the two categories (Jenrich & Sampson, 1990).

The second measure of discriminability was shown in a classification matrix. Each token of a given vowel was classified into the category with the highest posterior probability. A properly classified case was assigned a value of 0 and a misclassified case was assigned the value of 1.00. There were chances of this matrix providing an "overly optimistic estimate of the probability of misclassification". To reduce this bias, a jackknifed validation procedure was used to reclassify all the cases. This procedure involved the classification of each case into groups with the highest posterior probability, but this time, according to classification functions computed from all the data except the case being classified.

RESULTS

The default stepping criteria yielded the variables F2/F1/A2/Dur/A1 as the classification function that best separated the [± ATR] categories (Table 3.6). The [+ATR] vowels generally had lower F1s, A1s, and A2s than their [-ATR] counterparts, but higher F2s and longer durations. The F2/F1/A2/Dur/A1 function resulted in 79.7% correct classification of the vowels.

Table 3.6 also shows the classification functions for the pairs of [±ATR] vowels. The variables in the classification function, appear from left to right in the descending order of size of their F ratios. F1 was very consistent in the separation of the vowel pairs. Except for the e/ɛ pair, F2 and duration also, to differing degrees, consistently separated the [±ATR] pairs. The [+ATR] vowels had lower F1s but higher F2s than the [-ATR] vowels.

TABLE 3.6: CLASSIFICATION FUNCTIONS FOR ALL VOWELS AND [±ATR] PAIRS

Vowel	Classification function	F ratio	% correct id.
[±ATR] classes	F2,F1,A2,Dur,A1		79.7
i/ɪ	F1, A2, F2, A1, Dur	134.14	96.4
e/ɛ	F1, A1, A3	324.85	100.0
æ/a	F1, F2, Dur, F3	127.63	97.5
o/ɔ	F1, F3, A0, F2, Dur	529.14	100.0
u/ʊ	F1,F2, Dur,F3	164.35	97.5

The Jackknifed classification matrix (Table 3.7) shows the identification rates for the individual vowels in a F2/F1/A2/Dur/A1 classification function. For each ATR pair, that is, vowel pairs that differed only in ATR value, there tended to be very little or no misclassification.The most misclassification occurred with the vowel pairs which were previously found to overlap in F1 space (Hess, 1992),

/ɪ,e/, and /ʊ,o/: 21 of 85 cases of /ɪ/ classified as /e/; 26 of 83 cases of /e/ classified as /ɪ/; 19 of 82 cases of /o/ classified as /ʊ/; 16 of 74 cases of /ʊ/ classified as /o/. These cross height overlapping pairs had different classification functions (Table 3.8): /ɪ,e/, had Dur/A0 and /ʊ,o/ had F1/B1/F2/Dur (this implies that /ʊ,o/in this data do not overlap in F1 space).

TABLE 3.7: JACKKNIFED CLASSIFICATION MATRIX FOR F2/F1/A2/Dur/A1 CLASSIFICATION FUNCTION

CAT.	% C.C[5].	NUMBER OF CASES CLASSIFIED INTO GROUPS									
		i	ɪ	e	ɛ	æ	a	ɔ	o	ʊ	u
i	91.5	75	4	3	0	0	0	0	0	0	0
ɪ	72.9	2	62	21	0	0	0	0	0	0	0
e	57.8	2	26	48	0	0	0	0	0	0	0
ɛ	88.0	0	0	0	73	9	1	0	0	0	0
æ	79.0	0	0	0	12	64	5	0	0	0	0
a	92.8	0	0	0	2	2	77	2	0	0	0
ɔ	100.0	0	0	0	0	0	0	91	0	0	0
o	56.9	0	0	0	0	0	0	0	41	19	12
ʊ	72.7	0	0	0	0	0	0	3	16	56	2
u	80.5	0	0	0	0	1	0	0	14	0	62
TOTAL	79.7										

TABLE 3.8: CLASSIFICATION FUNCTIONS OF THE OVERLAPPING VOWELS

Vowel	Classification function	f ratio	% correct id.
e/ɪ	Dur/A0	19.10	73.1
ʊ/o	F1/B1/F2/Dur	48.24	85.3

5 "C.C." refers to 'correct classification'.

The degree of overlap was reflected in the relatively small size of the F ratios of these pairs. They were all less than 50.00, /ɪ,e / = 19.10 and /ʊ,o/ = 48.24. These values are relatively small compared with the smallest F ratio of the [±ATR] pairs, /u,ʊ /= 107.4

In the second type of discriminant analysis, the controlled stepping criteria enabled the investigator to determine the level of contribution of specific variables to distinguishing the harmony classes. F1/F2/F3 served as the benchmark classification function (BK). These variables were selected because, traditionally, they are accepted as the primary determinants of vowel quality. Table 3.9.1 isolates the individual effects of the variables that occur in Tables 3.6 and 3.8. It shows the effect of the variables on the overall percentage of correct classification (C.C.) of all the vowels, the relative distance (F ratio) between the overlapping front vowels and also their individual identification rates (Table 3.9.1).

TABLE 3.9.1: CLASSIFICATION EFFECTS OF CF VARIABLES IN TABLES 3.6 AND 3.8

STEPS	CF	overall % C.C.	change in % CC	f ratio ɪ/e	% CC ɪ/e
1	Benchmark (BK)	75.6	-	0.45	52.9/48.2
2	BK + B1	75.9	+0.3	0.36	52.9/50.6
3	BK + dur	78.6	+3.0	8.33	71.8/60.2
4	BK + A0	77.5	+1.9	4.97	48.2/67.5
5	BK + A1	77.7	+2.1	2.86	48.2/54.2
6	BK + A2	74.7	-0.9	0.48	50.6/48.2

Table 3.9.2 shows the idividual subject percentage correct classification of the overlapping vowels /e,ɪ/ for steps 2 and 3 of Table 3.9.1. The identification rates for the individual subjects indicated that generally, B1 did not affect their identification of the overlapping vowels, /ɪ,e/. On the other hand for five of the subjects, duration increased their identification rates for these vowels. This is further indication that the B1 distinction does not hold across several speakers.

TABLE 3.9.2: IDENTIFICATION RATES /ɪ,e/
FOR INDIVIDUAL SUBJECTS

SUB	F1/F2/F3 (BK)	%CC ɪ/e BK + B1	%CC ɪ/e BK + DUR
AAS	17.39	17.39	47.83
FB	86.36	86.36	77.27
GA	45.45	45.45	68.18
IA	72.72	72.72	63.63
PK	62.5	62.5	87.5
JO	63.63	63.63	63.63
NA	55.31	53.19	65.96
SF	86.36	86.36	77.27
YO	45.83	45.83	58.33

Table 3.10 presents the cumulative effect of the variables (Table 3.9.1) on the benchmark classification function (F1/F2/F3). The variables were stepped in descending order of the magnitude of their F ratio. That is, at each step the variable with the highest F ratio was introduced into the analysis.

TABLE 3.10: CUMULATIVE EFFECTS OF VARIABLES

Steps	CF	% C.C.	change in % CC	f ratio ɪ/e	% CC ɪ/e
step 1	Benchmark	75.6	-	0.45	52.9/48.2
step 2	step 1 + A2	74.7	-0.9	0.48	50.6/48.2
step 3	step 2 + A1	75.7	+1.0	2.29	49.4/54.2
step 4	step 3 + dur	79.9	+4.2	6.63	74.1/55.4
step 5	step 4 + A0	81.4	+1.5	6.97	80.0/61.4
step6	step 5 + B2	81.8	+0.4	6.13	80.0/61.4
step 7	step 6 + A3	82.3	+0.6	6.48	77.6/69.9
step 8	step 7 + B3	83.0	+0.7	5.97	77.6/72.9
step 9	step 8 + B1	83.5	+0.5	5.[illegible]	77.6/74.9

In both Tables 3.9.1 and 3.10, duration caused the most change in the overall identification rates. In Table 3.9.1 it caused a 3.0% increase, from 75.6% to 78.6%. The increase in Table 3.10 is 4.2%, from 75.7% to 79.9%. B1 does not play any significant role in the separation of the harmony classes. In both situations, contrary to Hess' conclusions, it increases the overlap between the /ɪ, e/ pair, which is reflected in their decreased F ratio. In Table 3.10, B1 consistently had the smallest F ratio, thus it was entered (step 9) only after all the other variables had been entered.

CONCLUSIONS

Given the above results, it can be concluded that the two phonological sets of vowels are separate acoustically and a classification function of F2/F1/A2/Dur/A1 generally separates the two harmony sets to some extent. It has also been found that when more data are examined the [±ATR] pairs show a clear cut and significant difference in duration and this difference generalizes over several subjects. The B1 difference, on the other hand, is not as significant as reported by Hess and does not generalize across a larger sample of speakers. Also the overlapping vowels /ɪ,e/ were generally separated more effectively by duration than by B1, contrary to that reported by Hess.

Although these results generally support some of the findings reported in the literature, there is ample evidence to suggest the distinction between [±ATR] vowels is marked by several acoustic correlates.

CHAPTER FOUR : GENERAL DISCUSSION AND CONCLUSION

It has been proposed that the primary articulatory difference between the two sets of vowels in the Akan harmony system is a retracted/advanced tongue root position and a raised/lowered larynx (Ladefoged,1964; Stewart,1967; Lindau, 1975, 1979). [+ATR] vowels are characterized by an advanced tongue root and lowered larynx, which result in an expanded pharyngeal cavity. [-ATR] vowels on the other hand, are characterized by a retracted tongue root and a neutral larynx, which results in a contracted pharyngeal cavity. In attempting to find an acoustic correlate for this feature, researchers have not only sought to find a single acoustic correlate but also tended to focus on one property of the entire articulatory movement underlying the feature. Consequently, different researchers have often come to different conclusions. Although the results of this present study support a number of these findings, they also show that, to properly define the acoustic marker of ATR, one needs to take into account the individual roles played by various acoustic parameters.

ACOUSTIC MARKER OF ATR: EARLIER CONCLUSIONS

Lindblom & Sundberg (1971), in accounting for the acoustical consequence of an increased pharyngeal cavity, looked at the effect of lowering the larynx. They report an overall lowering of all formant frequencies, when the larynx is lowered. They argue that "the simulated larynx lowering corresponds to an increase of the pharynx cavity length, and thus also of the total vocal-tract length"(1971:1176). This consequently, results in a lowering of all formant frequencies, particularly those that can be regarded as having a back-cavity resonance. Although there are small F1 frequency variations (5% - 6%), they claim that F2 is still the most sensitive in terms of percentage change, particularly on front vowels. The effect of an increased pharyngeal cavity is strongest for front vowels. Following their conclusions, [+ATR] vowels with the expanded pharyngeal cavity will be expected to have lower F2s. Our results, indeed, indicate changes in F2 frequencies for the [+ATR] vowels. The direction of changes, however, is contrary to what is predicted by Lindblom & Sundberg. The [+ATR] vowels with the expanded pharyngeal cavity had higher F2s (Table 3.2.1).

Halle & Stevens (1969) on the other hand, propose changes in F1 as the most consistent acoustical consequence of variations in vocal tract configuration due to changes in tongue root. This change in F1, they argue, can be observed from the acoustic data as well as predicted on a theoretical basis (perturba' 'on theory). In a vowel neutral position, the area of an acoustical tube (equivalent to the glottis of the vocal tract) would have a distribution of volume velocity maximum (node) for all natural frequencies. When a constriction occurs at the sealed end of the tube (the region equivalent to the larynx) all the formant frequencies are raised. On the other hand, if the area expands, the natural frequencies would be lowered. Translating this to the vocal tract, Halle & Stevens suggest that, because the volume velocity maximum of the first formant extends over at least the lowest 4 cm of the vocal-tract, a perturbation in the glottis region resulting in an expansion of the pharyngeal cavity at that point, would cause F1 frequency to be lowered. There would also be a small change in F2 frequency because the volume velocity maxima for F2 extends about 4 cm for back vowels and 2 cm for front vowels in the region. Consequently [+ATR] back vowels would have a lower F2 whilst [+ATR] front vowels would be expected to have higher F2s. Although this predicted F2 change does not hold up in some languages, for example, Igbo (Ladefoged, 1964), it does, to some degree, in this present study. Table 3.2.1 shows the predicted lowering of F2 frequencies for all [+ATR] vowels except /o/.

Lindau (1979) is also of the view that F1 is the most reliable acoustic marker of the ATR feature. As discussed earlier (chapter 2), F1 alone is not a reliable measure of tongue root advancement. This is because of its affiliation with the tongue height of front vowels and point of maximal constriction of back vowels. In other words it would be difficult to attribute convincingly the differences in F1 frequencies of vowel pairs of differing height to their ATR value. This "conflict of interest" by F1 may be resolved in two ways. One would be to look for acoustic correlates that are unique to ATR. The alternative would be to ignore the need for acoustic correlates and focus only on the articulatory mechanisms that underlie the distinctive feature. This alternate position is not acceptable because it is based on dubious assumptions. First it wrongly assumes phonological features to be articulatorily based and, secondly, in situations where there are other cues, it assumes the primacy of articulatory gestures over all other cues. It also assumes the mapping between articulatory gestures and acoustics to be arbitrarily complex.

However, in the face of mounting research evidence about the relative acoustic invariance of speech, it would be better to assume the position adopted by Nearey (1990) that, "a phonetic segment is a set of relatively similar articulatory patterns that maps into a set of relatively similar acoustic patterns that is furthermore distinct from the sets of patterns produced by other segments". This position assumes that the relationship between acoustics and phonetic gestures is not wholly arbitrary. It also means that independent articulatory gestures are learned as part of the sound system of a language and would have observable acoustic consequences that would set it apart from other classes of sounds in the language. Although Nearey leaves open the question of distinctive features, his position may still be adapted to describe the relationship between the articulatory mechanisms underlying some distinctive features and their acoustic correlates. One would thus expect the tongue root gestures underlying the ATR feature to have distinct acoustical consequences, a coherent set of acoustic property(ies) that clearly set the [+ATR] vowels aside from [-ATR] vowels. The results of this study indicate that tongue root advancing is generally characterized by a combination of acoustic properties --- F1, F2, amplitude of F1, F2 and duration.

Hess (1987,1992) suggests F1 bandwidth to be the most consistent measure of ATR differences, that is, "the bandwidth of the first formant (B1) proved to be the easiest to measure and moreover showed consistent difference between high and mid vowels which belong to different harmony sets" (1987:64). The [-ATR] vowels had bandwidths that were twice as wide as those of the [+ATR] vowels. She reports a 33% difference between the F1 bandwidths of cross-height overlapping pairs /ɪ, e/ and a 66% difference for /ʊ, o/.

TABLE 4.1: BANDWIDTH DIFFERENCES BETWEEN HARMONY PAIRS

Vowels	Bandwidth (in Hz)	Percentage difference
i/ɪ	76.4/56.7	+19.7%
e/ɛ	54.2/69.2	-15.0%
æ/a	70.2/88.7	-18.5%
o/ɔ	56.7/82.6	-25.9%
u/ʊ	81.8/73.9	+7.9%

Her findings are partly confirmed by this present study. The non-high [-ATR] vowels have a wider bandwidth than their [+ATR] counterparts. However, with the high vowels /i,ɪ,u,ʊ/, this is reversed (Table 4.1). The difference between the F1 bandwidth of the cross-height overlapping pairs are not as high as she suggests (Table 4.2)

TABLE 4.2: BANDWIDTH DIFFERENCES BETWEEN OVERLAPPING VOWELS

Vowels	Bandwidth	Percentage difference
e/ɪ	54.2/56.7	-2.5%
o/ʊ	56.7/73.9	-17.2%

Although our results indicate F1, F2, F1/F2 amplitudes and duration as the acoustic properties that generally separate the harmony classes, Hess' bandwidth conclusions can not be safely dismissed. This present study shows that some speakers use the B1 distinction. It is probable that a given speaker, manipulates different aspects of the spectra in addition to F1 to implement the [±ATR] contrast.

The argument could be made that our conclusions differ from Hess' as a result of the different experimental procedures and conditions, used. Fair though this argument seems, it however questions the reliability of bandwidth as an invariant acoustic property of ATR. If bandwidth is that sensitive to changes in experimental procedures and conditions then it is not a reliable acoustic measure of ATR. Also, the Asante dialect used in this study is so close genetically to the Kwahu dialect studied by Hess (Dolphyne, 1988), that one should not find such significant differences in the acoustic properties of their vowels due to dialectical differences.

TENSE/LAX AND ATR

The strong effect of duration in this study leads one to wonder if the tense/lax feature as it occurs in English is not the same as or at least similar to the ATR feature in Akan. These two types of features have been considered as being different (Stewart,1967; Lindau,1979; Ladefoged & Maddieson, 1990). ATR is supposed to occur mainly in African languages and the tense/tax distinction, in Germanic languages. [±ATR] vowels and the tense/lax vowels both differ in the tongue root position and tongue height. There is, however, supposed to be a correlation between the tongue root position and vowel height in the tense/lax vowels that is non-existent in the [+ATR] vowels. With the tense/lax vowels, tongue height and tongue root are not independently controlled parameters (Harshman, Ladefoged & Goldstein, 1977; Ladefoged & Harshman, 1979). Ladefoged & Maddieson (1990) argue that unlike English tense/lax vowels, the changes in tongue height for ATR vowels are "small in comparison with the expansion that occurs in the pharyngeal region". Lindau (1979) presents evidence that suggests that tongue height and tongue root position are not independently controlled in ATR vowels. She suggests that variations in tongue height in Akan can be predicted statistically from the tongue root position. This implies a correlation between these two articulatory gestures, a correlation similar to that which is found in the tense/lax vowels of English.

Given that similar muscles are involved in the production of both ATR and tense/lax vowels (Hockets, 1958; Stewart, 1967), if one assumes that there is invariance in speech production and perception (Nearey, 1990), it could be argued that the difference between ATR vowels and tense/lax vowels is one of a variation on an articulatory gesture, a variation that may be attributed to the forces of sound change. It may be further argued that since some harmony systems are known to have lost their phonetic basis as a result of historical change (Anderson, 1980), it is possible that the duration difference that once served as the acoustic basis of Akan vowel harmony is eroding due to sound change. This would explain the rather weak showing of duration of the harmony pairs but the strong separating effects it has on the cross height overlapping vowels and vowel categorisation in very restricted contexts. This articulatory variation may have resulted in changes in acoustical cues, namely the loss or reduction in the differences in duration that separate the harmony classes. The differences in duration found in this study give support to this argument. In English, lax vowels have a shorter duration than tense vowels. The average difference between the tense and lax vowels approaches 50 -100 msec (House, 1960). Our result shows duration as the fourth factor that separates the harmony classes. The difference between the cross height overlapping [±ATR] vowels is 27 msec. Although this difference is relatively smaller than that found between the tense and lax vowels in English, it nonetheless constitutes nearly 30% of the duration of the shorter vowels. As such it would seem clearly to exceed the conservative bounds on duration perception reported by Lehiste (1970: 12, Table 1).

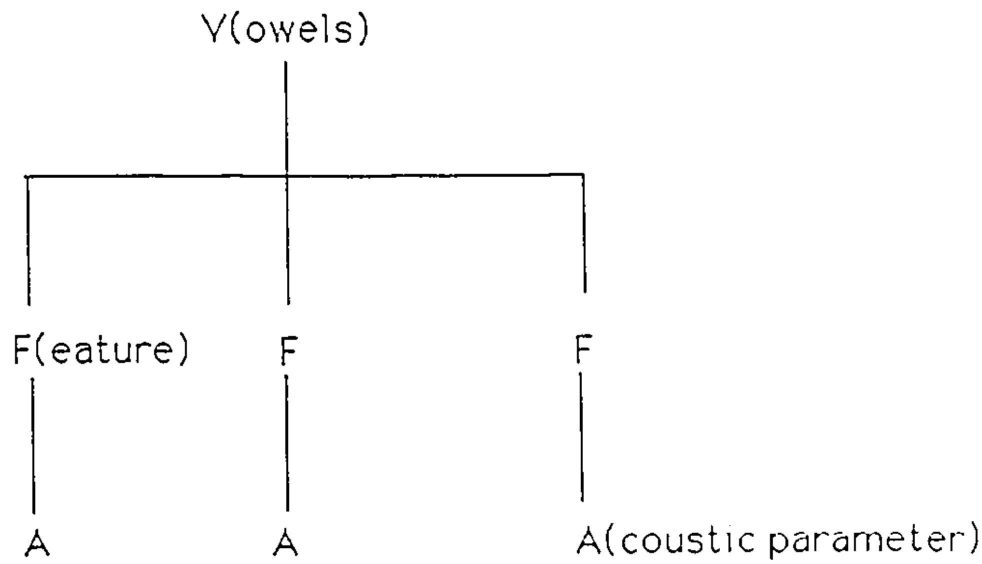
What then does one make of the findings of the previous studies? It is the opinion of this author that they cannot be completely set aside as invalid. Many previous findings have been confirmed in this present study. However on their own, they do not tell the entire "acoustic story" of the ATR feature. Looking at the significance of duration, F1, F2 and F1/F2 amplitude and to a lesser extent B1 in the classification of the vowels, it is suggested that to give a proper account of the nature of the acoustic correlate of ATR, the role of all these parameters must be considered. To do this, one needs to look at various ways in which acoustic cues may be related to phonological features and determine which model best describes the ATR phenomena.

PHONOLOGICAL FEATURES AND THEIR ACOUSTIC CORRELATES

One possibility of relating phonological features to their acoustic correlate(s) would be to take the Distinctive Theory approach, namely, assuming a one-to-one correspondence between the feature and its acoustic parameter (Jakobson, Fant & Halle, 1952; Chomsky & Halle, 1968; Halle & Stevens, 1970, 1971; Stevens, 1983). Within this framework, a feature is assigned a single, measurable physical correlate (Fig 4.1). In determining the marker(s) of the ATR feature, one must aim at finding a single coherent acoustic property that is sufficient in separating the [±ATR] classes and has very little impact on the other vowels in the language.

This property would be unique to the ATR feature only. If such an approach is accepted, then the works of Stevens and Halle (1969), Lindblom & Sundberg (1971), Lindau (1979), and Hess (1987, 1992) can be considered as being in the right direction. Although they all arrive at different conclusions, they have sought to find a single correlate for the feature (one-to-one mapping as in Figure. 4.1), for example F1 and F2. If it is determined that F1 is the acoustic marker of ATR, F1 can not be used to mark Height or any other feature difference in the language.

FIGURE 4.1: ONE-TO-ONE MAPPING BETWEEN PHONOLOGICAL FEATURES[6] AND THEIR ACOUSTIC CORRELATES (after Lindau & Ladefoged,1986)



Theoretically, this one-to-one constraint serves a good purpose. It ensures the universality of the feature, allows one to capture linguistic universals that would otherwise have been lost and avoid duplication in the marking of similar phonological patterns and structures. There are unfortunately some problems with this approach that makes it unacceptable.

Firstly finding such one-to-one relationships in natural languages is rare (Fant, 1984). Phonological features are often defined by several physical parameters (parameters which are often conditioned by physiological, linguistic and non-linguistic factors). Secondly, the physical correlates are not always unique to a single feature. For example, duration often serves as an acoustic marker of stress, tenseness and vowel length.

An alternative approach would be to find some acoustic correlates that are consistent and primary to ATR feature but at best are weak secondary cues to other phonetic features. We may, for example, determine that bandwidth and duration are the primary correlates of ATR but are secondary in general vowel identification.

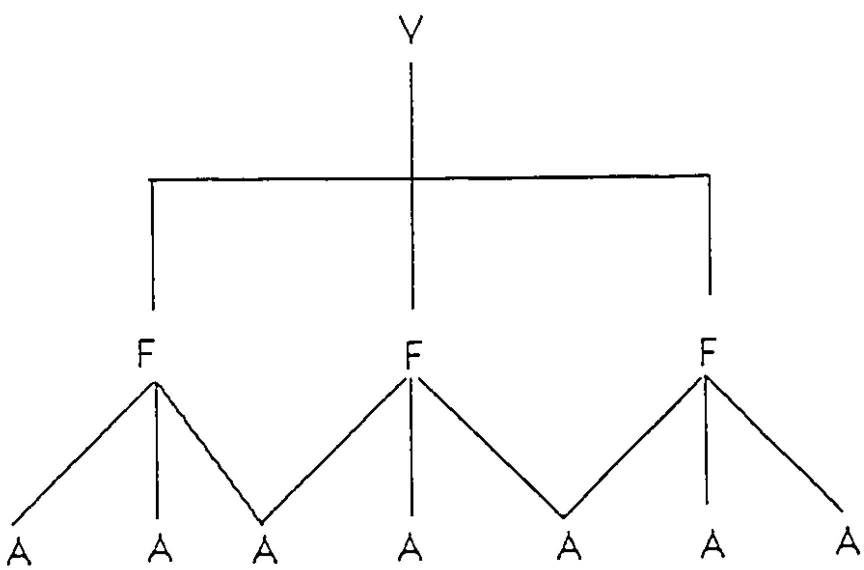
---

6 The relationship between the features and also the acoustic parameters is not necessarily one of independence.

This type of relationship assumes a many-to-many mapping between the phonological features and their physical correlates, in which some of the links are relatively weak.

One problem with this model with regards to our results is that the parameters in the classification functions are not consistent for the different pairs of [±ATR] vowels (Table 3.6 and 3.8) For example /i,ɪ/ is separated by F1/A1/F2/A2 whereas /o,ɔ/ is distinguished by F1/F3/A0/F2/dur.

FIGURE 4.2: MANY-TO-MANY MAPPING BETWEEN FEATURES AND THEIR CORRELATES (after Lindau & Ladefoged,1986)



A third alternative is to find gestalt of cues that are shared by other feature distinctions. This would mean that a feature would share many correlates with many other features ---- a complex many-to-many mapping between phonological features and their physical correlates (Figure 4.2). This concept was first proposed by Ladefoged (1981) and has been adopted by several other phonologists and phoneticians. An acoustic parameter is not considered unique to any given feature but rather contributes to various features in differing degrees. For example, feature X is defined by a% of parameter 1, b% of parameter 2 and c% of parameter

3. Feature Y on the other hand is defined by d% of parameter 1, a% of parameter 2 and e% of parameter 3.

This is often the situation in many languages. Lindau & Ladefoged (1986) note that the acoustic correlates of phonological features vary across and within languages. As was noted earlier, there are appear to be some best variations in the combinations of parameters that best distinguish the different pairs of [±ATR] vowels (Table 3.6 and 3.8). Consequently, the specific acoustic characteristics of vowel harmony not be statable in absolute terms, but only by comparing one vowel relative to another and also one speaker relative to another. Whereas, for example, ATR is characterized by F1/A1/F2/A2 in an /i,ɪ/ distinction, it is marked by duration/A0 in an /e,ɪ/ distinction. It is apparent that ATR draws on several acoustic parameters to differentiate the different vowels. To this end, it is being proposed that ATR be considered a "cover feature".

ATR AS A COVER FEATURE

"Cover Feature" was originally used to refer to precisely those features that had no measurable physical correlates but which "covered" a class of sounds (Sommerstein, 1977, as discussed by Clark & Yallop, 1991). Lindau & Ladefoged (1986) also use the term to mean a phonological label for a bundle of articulatory and acoustic properties. It is this meaning that is applied to ATR when it is labeled a "cover feature" in this analysis. ATR is therefore being considered a cover feature to the extent that, acoustically, it provides a convenient label for a combination of several "acoustic measures" that distinguish the two classes of vowels involved in the phonological process of vowel harmony. The parameters F1, F2, A1, A2, and duration combine in different ways to mark ATR. The members of the classification function often share 'functional' relationships which can sometimes be predicted theoretically. For example the relationship between the members of the classification function F1/F2/A1/A2, an increased F1 and decreased F2 (as is the case for the [-ATR] vowels) results in the distance between the two formants being reduced. The high frequency "skirt" of F1 will boost the F2 causing both of their amplitudes to increase (Kent & Read, 1992).

The relationship between the vowels of a harmony class is thus more of a "family resemblance" (Lindau & Ladefoged, 1986). This means that although the acoustic properties of the members of a harmony class are varied, in the presence of other vowels in Akan, they perform a coherent phonological function.

CONCLUSION

This study has explored the following: a) Whether F1 bandwidth correlates with the [±ATR] value of a vowel across several speakers of the Asante dialect; b) Whether F1 bandwidth consistently distinguishes the cross-height overlapping pair /e,ɪ/; and c) Which variables are suited for use as discriminatory criteria for separating the vowels into [±ATR] harmony classes?

On the basis of the results obtained, it is suggested that the F1 bandwidth distinction does not generalize over several speakers. Furthermore, it is not reliable across subjects for the distinction of the cross-height overlapping vowels. It is also proposed that the distinction between the two vowel harmony classes in Akan is not only phonologically real but also acoustically real. However, the [ATR] feature that serves as the phonetic basis of this harmony is not marked by a single acoustic correlate as has been proposed by Halle & Stevens (1969), Lindblom & Sundberg (1971), Lindau (1979), and Hess (1987, 1992), but rather by a combination of correlates which includes F1, F2, F1/F2 amplitudes and duration. The nature of the combinations vary from vowel to vowel and also from speaker to speaker. It is further suggested that on this basis, ATR be considered acoustically as a cover feature.

To be able to give a full account of the acoustic nature of some vowel harmony systems, researchers may in future need to look at the relative contribution of multiple acoustical parameters and determine the extent to which these parameters support the harmony system.

REFERENCES

Anderson, S.R. (1980). Problems and Perspective in the Description of Vowel Harmony. In R. Vago (Ed.) Issues in Vowel Harmony. pp. 1-48. Amsterdam: John Benjamins B.V.

Andoh-Kumi, K. (1979). Akan kasa nnyegyeee ho adesua bi (a phonology of Akan). Cape Coast, University of Cape Coast.

Aoki, H. (1968). Towards a typology of vowel harmony. International Journal of American Linguistics. 34:142-145

Assaman, P. (1979). The role of context in vowel perception. Unpublished MSc thesis, University of Alberta, Edmonton, Alberta.

Berry, J. (1957). Vowel Harmony in Twi. Bulletin of School of Oriental and African Studies. 124-130

Boadi, L.A. (1963). Palatality as a Factor in Twi Vowel Harmony. Journal of African Languages. 2:133-138.

Chomsky, N., & Halle M. (1968). The Sound Pattern of English. New York: Harper & Row.

Clark, J., & Yallop, C. (1991). An Introduction to Phonetics and Phonology. Oxford: Basil Blackwell.

Clements, G.N. (1981). Akan vowel harmony: a nonlinear analysis. Harvard Journal of Phonology. 2,108-177.

Crothers, J., & Shibatani, M. (1980). Issues in the description of Turkish vowel harmony, In R. Vago (Ed.) Issues in Vowel Harmony. pp. 62-88. Amsterdam: John Benjamins B.V

Dakubu, Kropp M.E. (1973). Ga-English dictionary. Ghana: Institute of African Studies

Dolphyne, F.A., & Kropp Dakuba, E. (1988). The Volta Camoe Languages. In Kropp Dakuba (ed.) The languages of Ghana. pp. 50-90. London: Kegan Paul.

Dolphyne, F.A. (1974). Languages of Ghana-Ivory Coast Border. Colloque inter-universitaire Ghana-Cote d'Ivoire : les populations communes de la Cote d'Ivoire et du Ghana. Abidjan

Dolphyne, F.A., (1988).The Akan (Twi & Fante) language. Accra: Ghana Universities Press.

Fant, G. (1960a). Acoustic theory of speech production. The Hague: Mouton.

Flanagan, J.L. (1972). Speech analysis, synthesis and perception. New York: Springer-Verlag.

Greenberg, J.H. (1963). The languages of Africa. The Hague:Mouton.

Halle, M. & Stevens, K. (1969). On the feature 'Advanced Tongue Root'. MIT Research Laboratory of Electronic Quarterly Progress Report, 94, 209-215.

Harshman, R., Ladefoged, P., & Goldstein, L.(1977). Factor Analysis of tongue shapes. Journal of the Acoustical Society of America, 62, 693-707.

Hess, S. (1987). Acoustic characteristics of the vowel harmony feature and raising in Akan. UCLA Working papers in Phonetics, 68, 58-72.

Hess, S. (1992). Assimilatory effects in a vowel harmony system: an acoustic analysis of advanced tongue root in Akan. Journal of Phonetics, 20, 475-492.

House, A.S. (1958). On vowel duration in English. Journal of the Acoustical Society of America, 33, 1174-1178.

Jackson, M. (1988). Phonetic theory and cross-linguistic variation in vowel articulation. UCLA Working papers in Phonetics, 71,1-184.

Jakobson, R., & Halle, M. (1962). Fundamentals of Language. The Hague: Mouton.

Jakobson, R., Fant, G., & Halle, M. (1952). Preliminaries to speech analysis: distinctive features and their correlates. Cambridge: MIT Press.

Jenrich, R., & Sampson, P. (1990). Stepwise Discriminant Analysis. In W.J. Dixon (Ed) BMDP Statistical Software Manual: Volume 1. Los Angeles: University of California.

Kent, R.D., & Read, C.(1992). The Acoustic Analysis of Speech. San Deigo: Singular Publishing Group.

Ladefoged, P. & Harshman, R., (1979). Formant frequencies and movements of the tongue. In Lindblom, B. & Ohman, S. (Ed) Frontiers of speech communication (pp. 25-43). London: Academic Press.

Ladefoged, P., & Maddieson, I., & Jackson, M. (1988). Investigating phonation types in different languages. In O. Fujimura (Ed)Vocal physiology: voice production, mechanism and functions. (pp 297-317,) New York: Raven

Ladefoged, P., & Maddieson, I. (1990). Vowels of the world's languages. Journal of Phonetics, 18, 2, 93-122.

Ladefoged, P. (1964). A phonetic study of West African languages: and auditory-instrumental study. Cambridge: Cambridge University Press.

Ladefoged, P. (1975). A Course in Phonetics. New York: Harcourt Brace Javanovich.

Lehist, I. (1970). Suprasegmentals. Cambridge, Mass: MIT Press.

Lindau, M., & Ladefoged, P. (1986). Variability of feature specifications. In J.S. Perkell & D.H. Klatt (Ed) Invariance and Variability in Speech Processes (pp 456 - 478). Hillsdale NJ: Lawrence Erlbaum.

Lindau, M. (1975). Features for vowels. UCLA Working papers in Phonetics, 30, 1-155.

Lindau, M. (1976). Larynx Height in Kwa. UCLA Working papers in Phonetics, 31, 53-61.

Lindau, M. (1979). The feature expanded. Journal of Phonetics, 7, 163-176.

Lindau, M. (1987). Tongue mechanisms in Akan and Lou. UCLA Working paper in Phonetics, 68, 46-57.

Lindblom, B., & Sundberg, J. (1971). Acoustical consequences of lip, tongue, jaw and larynx movement. Journal of the Acoustical Society of America, 50, 1166 1179.

Markel, J., & Gray, A. (1976). Linear prediction of speech. Berlin: Springer Verlag.

Minifie, F.D., Hixon, T.J., & Williams, F. (1973). Normal Aspects of Speech, Hearing and Language. New Jersey: Prentice-Hall.

Nearey, T.M. (1980). On the physical interpretion of vowel quality: cinefluorographic and acoustic evidence. Journal of Phonetics, 8, 213-241.

Nearey, T.M. (1990). The segment as a unit of speech perception. Journal of Phonetics, 18, 347-373.

Nearey, T.M. (1993). A double-weak perspective on intermediate properties and trading relations (in press).

Painter, C. (1973). Cineradiographic data on the feature "covered" in Twi vowel harmony. Phonetica, 28: 97-120.

Rigen, C.O. (1980). A concrete analysis of Hungarian vowel harmony. In R. Vago (Ed) Issues in Vowel Harmony. Amsterdam: John Benjamins B.V.

Schacter, P. & Fromkin, V. (1968). A phonology of Akan : Akwapem, Asante and Fante, UCLA Working Papers in Phonetics Number,19, 3-269.

Schacter, P. (1962). Teaching English pronunciation to the Twi speaking student. Legon: Ghana University Press.

Stewart, J.M. (1966a). Comparative study of the Volta-Camoe Languages. Research Review 2.2. Ghana: Institute of African Studies.

Stewart, J.M. (1966e). Akan history: some linguistics evidence. Ghana Notes and Queries, 9.

Stewart, J.M. (1967). Tongue Root Position in Akan Vowel Harmony. Phonetica, 16: 185 - 204.

Stewart, J.M. (1971). Niger-Congo, Kwa. Current Trends in Linguistics, 7.

Vago, R. (1980). Issues in Vowel Harmony. Amsterdam: John Benjamins B.V.

Westerman, D., & Bryan, M.A. (1952). Languages of West Africa. Handbook of African languages Part 2. London: Oxford University Press (new edition with supplementary bibliography, 1970).

<u>APPENDIX I</u>

<u>AKAN CONSONANT CHART</u>

	labial		labio-dental		alveo-lar		alveol-palatal		palatal		velar		glottal	
plosive	p b	*p* *b*			t d	*t* *d*					k kʷ g gʷ	*k* *ku* *g* *gu*		
fricat-ive			f	*f*	s sʲ sʷ	*s* *si* *su*	ɕ ɕʷ	*hy* *hw*					h hʷ	*h* *hu*
affri-cate					t͡s d͡z	*ts* *dz*	ʨ ʨʷ ʥ ʥʷ	*ky* *tw* *gy* *dw*						
nasal	m	*m*			n	*n*			ɲ ɲʷ	*ny* *nw*	ŋ ŋʷ	*n* *nw*		
lateral					l	*l*								
trill					r	*r*								
glide	w wʸ	*w* *w*			r	*r*			y	*y*				

The orthographic forms shown in bold [7] . The secondary articulation, labialisation, plays an important role in the Akan consonant system. Other types of secondary articulation that are also used extensively in particularly the Asante dialect are

[7] The table is based on Dolphyne (1988:29). Modifications to the original include the use of phonetic symbols to represent the sounds, the relabeling of the bilabial class as labial, and the division of pre-palatal/palatal class into alveol-palatal and palatal classes.

palatalisation and labial-palatalisation (Dolphyne, 1988; Schacter & Fromkin, 1968).

APPENDIX II

WORD LIST FROM HESS (1987,1992)

	WORD	GLOSS	VOWEL	TONE
1.	asi	*adversary*	i	H
2a.	ase	*father-in-law*	ɪ	H
2b.	ase	*under*	ɪ	H
3.	ose	*a yell*	e	H
4a.	ɔsɛ	*a similarity*	ɛ	L
4b.	sɛsɛ	*shrimp*	ɛ	H
5a.	asabu	*menstruation*	æ	L
5b.	wo taku	*your measure of gold*	æ	H
6.	ɔsa	*war*	a	H
7.	oso	*a fine person*	o	H
8a.	ɔsɔ	*a shark* (unknown to speaker)		
8b.	asɔ	*a hole*	ɔ	H
9a.	esu	*a species*	u	H
9b.	osu	*yam*	u	H
10.	ɛso	*top*	ʊ	H

APPENDIX III

FORMANT FREQUENCY VALUES RECORDED BY HESS (1987)

FORMANT MEANS (n = 4)

FREQUENCY VALUES IN Hertz (Hz)

Vowel	F1	F2	F3	F4
i	260	2141	2678	3565
ɪ	309	1785	2438	3640
e	311	1875	2498	3605
ɛ	458	1564	2430	4000
æ	525	1570	2053	3523
ɑ	630	1319	2137	3460
u	306	780	2225	- - -
ʊ	410	1198	2195	3170
o	423	1293	2455	3360
ɔ	524	1108	2065	3415

APPENDIX IV

MEAN DURATION, OVERALL AMPLITUDE AND F1/F2/F3

BANDWIDTH/AMPLITUDE VALUES

VARIABLE	i	ɪ	e	ɛ	æ
DUR (MS)	92.74	81.20	105.28	114.51	82.99
A0(dB)	47.96	50.14	52.21	50.17	50.81
B1(Hz)	76.40	56.71	54.21	69.21	70.22
A1(dB)	67.28	74.82	77.08	75.81	75.94
B2(Hz)	109.00	102.29	107.84	104.16	111.15
A2(dB)	63.85	71.62	72.42	76.49	73.05
B3(Hz)	139.33	149.05	126.98	162.21	165.04
A3(dB)	64.43	68.43	71.51	70.71	68.52

VARIABLE	ɑ	o	ɔ	u	ʊ
DUR (MS)	96.67	109.78	104.40	118.13	105.27
A0(dB)	49.55	51.67	51.63	50.11	51.85
B1(Hz)	88.73	56.70	82.60	81.83	73.94
A1(dB)	75.66	76.48	77.65	71.07	75.69
B2(Hz)	115.54	87.92	96.73	152.12	100.48
A2(dB)	75.27	66.89	74.51	56.29	70.42
B3(Hz)	166.06	141.51	173.75	126.36	139.04
A3(dB)	61.74	55.32	60.66	53.09	59.11

APPENDIX V

STANDARD DEVIATIONS OF DURATION, OVERALL AMPLITUDE AND F1/F2/F3 BANDWIDTH/AMPLITUDE VALUES

VARIABLE	i	ɪ	e	ɛ	æ
DUR (MS)	27.19	25.62	32.48	29.64	16.67
A0(dB)	3.77	3.18	2.90	2.99	2.51
B1(Hz)	22.06	8.45	6.71	13.54	11.69
A1(dB)	5.49	4.49	4.25	4.54	3.62
B2(Hz)	43.80	28.78	47.69	30.04	29.44
A2(dB)	8.27	4.20	6.65	4.89	5.24
B3(Hz)	52.69	72.27	53.11	67.11	67.93
A3(dB)	12.19	9.39	6.20	6.34	5.62

VARIABLE	a	o	ɔ	u	ʊ
DUR (MS)	26.78	25.48	22.09	38.49	29.21
A0(dB)	3.23	3.62	2.49	3.62	3.40
B1(Hz)	25.49	8.33	47.08	67.95	19.93
A1(dB)	4.05	4.51	4.39	4.75	5.46
B2(Hz)	38.97	31.22	28.48	63.44	57.80
A2(dB)	3.58	7.75	4.68	6.65	6.04
B3(Hz)	67.47	57.77	82.34	76.42	66.52
A3(dB)	17.15	9.29	8.92	13.95	7.85