# The Glottalic Consonants of Hausa

by

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# Abstract

This thesis is concerned with the examination of the glottalic consonants of Hausa, a Chadic language spoken in northern Nigeria, Niger, Cameroon, Togo and Ghana. The glottalic consonants constitute a set of phonemes in the language whose historical and phonetic properties merit further investigation.

The study is laid out in three parts. Part one (Chapters 1, 2 and 3) is the historical section. Here, a general overview of the Hausa language is given. Also discussed are several specific points made by pioneers of the genetic classification of Chadic within Afroasiatic and the reconstruction of glottalic consonants in both Chadic and Afroasiatic. The discussion here is not new but presents a summary of the literature. Hausa native words that have glottalic consonants are compared with possible cognates from other related Chadic languages from West, Central and East branches of Chadic and also from other Afroasiatic languages.

Part two (Chapters 4 and 5) of the study concerns the investigation of phonation types in general. Chapter 4 gives a short account of the larynx, the mechanism of the vocal fold vibration and classification of phonation types. Chapter 5 is devoted to a review of instrumental techniques used in voice measurement.

Part three (Chapter 6, the instrumental section) presents and discusses the results of a detailed electro-laryngographic analysis of the activity of the behaviour of the vocal folds in the production of the glottalic consonants and their non-glottalic counterparts as observed in the speech of educated native speakers of the language. The chapter begins with a review of the literature reporting early instrumental and non-instrumental studies of the segmental phonemes of the language. This is followed by a description of the techniques used to record, display and annotate both speech pressure and laryngographic waveforms. Both qualitative and quantitative analysis of the waveforms are presented. The most important parameter in the quantitative analysis is estimated open quotient (OQ) derived from the Lx waveforms measurements of Fundamental Frequency, duration and Voice Onset Time are also given. The chapter concludes by presenting the results of the experiment:

1 OQ increases in anticipation of plain voiceless consonants, and is relatively high at the consonantal release;

2 OQ decreases in anticipation of laryngealized consonants including the glottal stop (for most speakers) and less sharply for the ejectives;

3 OQ remains approximately at the speaker's modal value for the plain voiced consonants;

4 The laryngealized segments tend to lower pitch at the left of the consonant; and

5 They also tend to be longer than their plain counterparts.

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# Dedication

This Thesis is dedicated to
Asabe, Saratu, Na'omi
and Yahaya.

# Acknowledgements

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A. Haruna,
London, February 1990.

# Notes and Transcription

1 Some of the terms/labels in the text have to be abbreviated to save space. Many of the abbreviations are self-evident, but in the event that an abbreviation is unclear, its expansion can be found here.

2 On the transcription of the data I have not adhered strictly to the transciption of each author for ease of typing. The glottalized consonants in Hausa are written as /b'/, /d'/, /ts/, /k'/ and /'y/ even in quotations. See below for alternative symbols for the data transcribed from other languages and non-glottalized segments in Hausa.

3 Tone is not marked on proper nouns and in chapters 1-3 on data which the original authors did not mark it.

4 A grave accent (`) above a vowel indicates that it has a low tone, e.g. màcè 'woman'. The accent is marked on the first vowel of the double vowel. A circumflex accent (^) above a vowel indicates that it has falling tone, e.g. mâi 'oil'. High tones are left unmarked.

5 ( ) with a segment enclosed, e.g. (h), means that the segment is not yet well established; without a segment enclosed means that there is a missing segment.

6 /sh/ is used in Hausa even in quotation to mean palato-alveolar voiceless fricative.

7 /?/ means correspondence is questionable.

8 * indicates protoform.

9 ** indicates protoforms for Chadic West-A in Lax (1986).

10 C<u>?</u> indicates any consonant plus glottal stop, e.g. /d<u>?</u>/ voiced alveolar stop plus glottal stop.

11 /aa/ = long vowel.

12 /a/ = short vowel.

13 C = any consonant.

14 /b'/ means /ɓ/ = glottalized bilabial stop.

15 /d'/ means /ɗ/ = glottalized aveolar stop.

16 /ts/ = alveolar ejective affricate.

17 /t'/ = dental voiceless ejective.

18 /c'/ = palatal voiceless ejective.

19 /k'/ means /ƙ/ = velar ejective.

20 /'y/ means glottalized palatal glide.

21 /'w/ means glottalized labial glide.

22 /ʔ/ = glottal stop.

23 /'J/ = palato-alveolar ejective.

24 E = /ə/ = schewa

25 E = /ɛ/ front, half-open unrounded vowel.

26 /ê/ retracted front, half-open unrounded vowel.

27 /å/ = voiceless front open unrounded vowel.

28 /ẹ/ = slightly raised front, half-close unrounded, vowel.

29 /ä/ = centralized open unrounded back vowel

30 /ŭ/ = non-syllabic overshort close back unrounded vowel.

31 /p'?/ means /ṕ?/ questionable bilabial ejective.

32 /O/ means /ɔ/ = half-open back rounded vowel.

33 /3/ means /ꜣ/. The hieroglyph depicting the Egyptian vulture.

34 /ã/ = nasalized vowel.

35 /Φ/ = voiceless bilabial fricative.

36 /ai/ = diphthongs.

37 /œ/ = half-open, front, rounded vowel.

38 /r̃/ = rolled r.

39 /ṛ/ = tap.

40 /ɽ/ means retroflex.

41 L means /ʟ/ = lateral approximant.

42 /X/ means /ɣ/ = voiced non-emphatic uvular fricative.

43 C' means glottalized consonant.

44 /ɷ/ = close back rounded vowel.

45 /lz/ means /ɬ/ = hlateral (lateral fricative).

46 /lz$^1$/ means /ɬ$^1$/ = hlateral (lateral fricative).
47 /lz$^2$/ means /ɬ$^2$/ = hlateral (lateral fricative).
48 /lZ/ means /lʒ/ = hlateral (lateral fricative).
49 /ky/ means /k$^y$/ = palatalized voiceless velar stop.
50 /kw/ means /k$^w$/ = labialized voiceless velar stop.
51 /gy/ means /g$^y$/ = palatalized voiced velar stop.
52 /gw/ means /g$^w$/ = labialized voiced velar stop.
53 /xy/ means /x$^y$/ = palatalized velar fricative.
54 /xw/ means /x$^w$/ = labialized velar fricative.
55 Y = front vowel in Lax (1986).
56 W = back vowel in Lax (1986).
57 V = unspecified vowel in Lax (1986).
58 -V unspecified final vowel of verbs in Lax (1986).
59 /NC/ = prenasalized consonant.
60 /ø/: this symbol is not a phoneme, but is a symbol used to represent the phonetic onset of word-initial vowels.
61 /@/ means [ɨ] close central unrounded vowel.
62 /I/ = close central unrounded vowel.
63 /ć/ = voiceless non-emphatic lateralized affricate.
64 /ç/ = voiceless palatal fricative.
65 /c/ = Alveolar palatal affricate.
66 /ṯ̣/ = retracted voiceless emphatic dental stop.
67 /b./ = long voiced bilabial stop.
68 /ṭ/ = voiceless emphatic[1] dental stop.
69 /ḍ/ = voiced emphatic dental stop.
70 /ṣ/ = emphatic dental affricate.
71 /ḳ/ = emphatic velar stop.
72 /ẓ/ = alveolar voiced emphatic affricate.
73 /ž/ = alveopalatal voiced fricative.
74 /x̣/ = emphatic velar voiceless fricative.
75 /š/ = alveolar voiceless sibilant fricative.
76 /ś/ = voiceless non-emphatic lateralized affricate.
77 /č/ = alveopalatal voiceless affricate.
78 /č̣/ = emphatic alveopalatal affricate.
79 /q/ = Arabic voiceless uvular plosive.
80 /ǧ/ = Arabic voiced uvular plosive

81 /ġ/ = emphatic velar plosive.

82 /ḥ/ emphatic (uvular fricative) epiglottal.

83 /ẖ/ voiceless non-emphatic, uvular fricative.

84 /ŋ/ = velar nasal.

85 /ṣ/ = post-alveolar, voiceless fricative.

86 Vl = voiceless.

87 Vd = voiced.

88 Pl = plosive.

89 / / = phonemic slashes.

90 [ ] = phonetic brackets.

91 /q/ > /k/ = /q/ becomes /k/.

92 /k/ < /q/ = comes from /q/.

93 b̲ = bilabial implosive.

94 ḍ' = alveolar implosive.

95 g' = velar implosive.

96 tʃ = alveolar affricate.

97 /ph/ = aspirated, voiceless, bilabial stop.

98 /bh/ = aspirated voiced, bilabial stop.

99 /ç/ = pharyngealized fricative.

1 The term "emphatic" is the conventional name of consonants with a dot under them and their etymological counterparts. In the languages of the AA family the "emphatics" are realized as glottalized, uvularized, pharyngealized, retroflex or aspirated (cf. Dolgopolsky (1977). It is not always clear which of the terms some of the authors cited in this work used.

2 Sound with a zero under or over it (e.g. [g̊]) indicates voicelessness (in other words it is devoiced).

# List of Chapters

**PART ONE: HISTORICAL**

**PART TWO: THE LARYNX AND VOICE MEASUREMENT**

**PART THREE: THE EXPERIMENTAL INVESTIGATIONS, SUMMARY AND CONCLUSIONS**

# PART ONE: HISTORICAL

# Chapter One

Some Background Information on Hausa.

## 1.1 General Introduction

This is a study of the glottalic consonants of Hausa a Chadic language spoken in northern Nigeria, Niger, Cameroon, Togo and northern Ghana. The glottalic consonants are chosen because they constitute a set of phonemes in the language whose phonetic properties and historical origin merit further investigation.

Chapter 1 is a general introduction and provides a brief sketch of the Hausa language, its geographical distribution, status in Nigeria, and phonology. The remainder of the study is divided into three parts. Chapters 2 and 3 constitute the historical part, providing a comprehensive overview of the genetic classification of Chadic within Afroasiatic and the reconstruction of glottalic consonants in Chadic and their counterparts in Afroasiatic. Correspondences between the glottalic consonants of Chadic and related Afroasiatic languages are given. No new theories are put forward, but critical comments on the plausibility of earlier treatments are made.

The second part of the thesis concerns the investigation of phonation types in general. Chapter 4 gives a brief account of the larynx and the mechanism of vocal fold vibration, with some consideration of the classification of phonation types. Chapter 5 provides an overview of instrumental techniques used in voice measurement.

Part three concerns the investigation of phonation types in Hausa. Chapter 6, the experimental chapter in the thesis, describes and presents the results of an instrumental investigation of the Hausa glottalic consonants. The main technique used was the electrolaryngography. Subjects were sixteen Hausa speakers, 15 males and 1 female, representing both East Hausa and West Hausa dialect areas. The last section of chapter 6, is the general conclusion.

## 1.2 Classification and Geographical Spread.

Hausa is a member of the Chadic family of languages in the Afroasiatic phylum that includes as its other branches, Berber, Semitic, Cushitic, Omotic and Ancient Egyptian. Fig. 1.1 is a tree diagram of the Chadic family including Hausa and its major dialects (cf. also map 1.1). For a detailed family tree of Chadic see Chapter 2 (section 2.4).

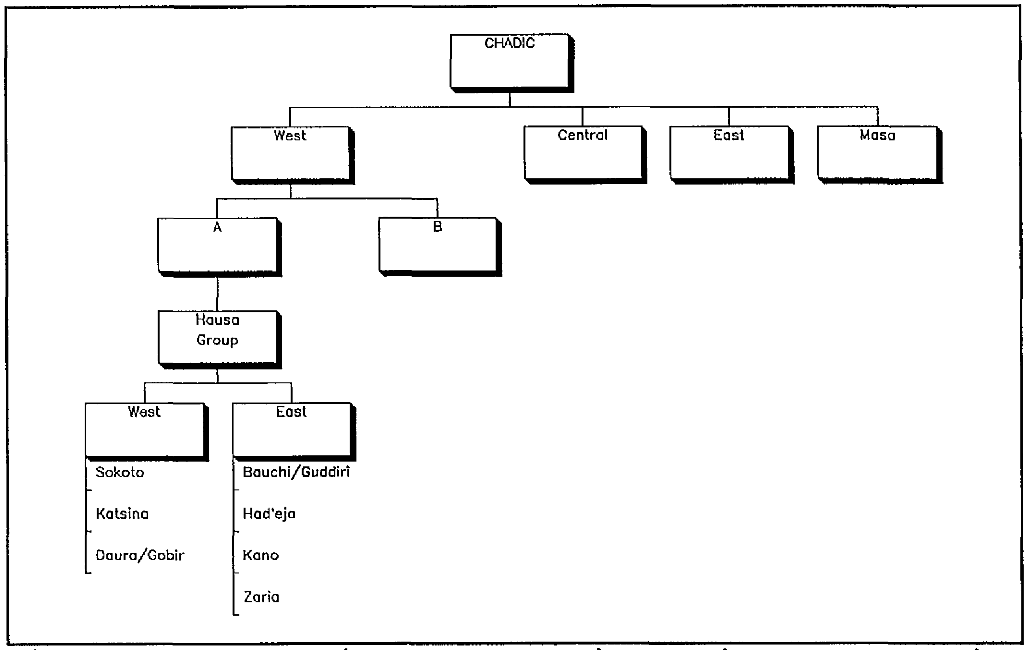



Figure 1.1: Tree diagram of Chadic showing Hausa and its main dialects.

Within Chadic there are over 140 languages (cf. Fleming 1983:19) of which Hausa is the most widely spoken. In some of the northern states of Nigeria Hausa is spoken as a first language. It is estimated that there are between 25 and 30 million people living in northern Nigeria, Ghana, Cameroon and southern Niger who speak the language as their mother tongue. A further 20 million may speak it as their second language (cf. Furniss and Jaggar 1988).

In some of the northern states of Nigeria, Hausa is used as a lingua franca. In diaspora, Hausa is spoken in several neighbouring countries. For example, on the eastern border of Nigeria, Hausa is spoken in northern Cameroon. On the northern border of Nigeria, Hausa is spoken in Niger Republic and West-Central Chad, and to the west in the Republic of Benin, northern Togo, and northern Ghana. Hausa is also spoken in communities of settlers in urban centres in Senegal, Libya, Sudan, Ivory Coast and Zaire.

Within the Chadic family Hausa is the language which is best documented. In the last 100 years, the language has been the subject of serious linguistic study (cf. Hair 1967 for a comprehensive list of early studies on Hausa). The first grammar of the language appeared in 1862 and a dictionary in 1876, both by Schön. Since then the study of the language has been developing rapidly. It would be beyond the scope of this work to list all works on the subject. For an extensive bibliography of writings on Hausa linguistics and literature covering the earliest times of the language study to 1977 see Baldi (1977), and for the period covering 1976-86 (see Awde 1988) (this list includes a number of items not found in Baldi 1977).

As a language, Hausa has a recognised importance. It is taught in universities in Africa (mainly in universities of northern Nigeria and Niger Republic). It is also taught in universities in Europe and North America. Hausa is broadcast and transmitted on local and national radio and television stations both within Nigeria and Niger. Internationally, it has a slot in a number of established foreign radio stations. Programmes in Hausa are broadcast by the external services of the British Broadcasting Corporation (BBC) London, Voice of America (VOA), Voice of Germany (Deutsche Welle), Radio Cairo, Radio Peking (China) and Radio Moscow. In the continent of Africa south of the Sahara it is as widely spoken as Swahili. In West Africa the Hausa language is fast spreading as a lingua franca.

Under the Government of the former Northern Region of

Nigeria, Hausa has shared official status along with English (cf. Kraft and Kirk-Greene 1973). In 1979, Hausa was recognized as one of the three major languages of Nigeria (the other two are Igbo and Yoruba) and incorporated in the 2nd schedule of the Nigerian Constitution, although it does not enjoy the status of national and official language.

## 1.3 Dialects.

Since this is not a work on dialectology, I am not going to go into much detail, beyond what is relevant to this work. In spite of its relatively large geographical distribution, to my knowledge the dialects are mutually intelligible. However within the phonological systems of the various dialects there are some interesting differences (cf. Ahmed and Daura (1970), Bello (1972), Dogo (1977), Zaria (1982) and Abubakar (1983)).

Bargery (1934) classified the language into two groups which he called the "Kano dialect" and "Sokoto dialect." The Kano dialect is usually accepted as "Standard" Hausa. Ahmed and Daura (1970) used the terms "Classical" (to mean the Sokoto dialect) and "Modern" (to mean the Kano dialect) of Hausa. Dogo (1977) adopted the use of the terms "West" (i.e the type of Hausa spoken in the former Sokoto and Katsina provinces of Nigeria and neighbouring French territories) and "East" (i.e the type of Hausa spoken in the former Kano, Zaria, and Bauchi provinces). Following Dogo, I have decided to adopt the terms "West" and "East".

Within the two major divisions in Nigeria, seven major dialects of Hausa have been recognized, as well as many minor dialects. Most of the dialects centre around a major city. For instance, Sakkwatanci (Sokoto dialect) is spoken mainly in Sokoto and the surrounding towns, Kananci (Kano dialect) is spoken mainly in Kano and the surrounding towns, Katsinanci (Katsina dialect) is spoken mainly in Katsina and the surrounding towns and Zazzaganci (Zaria dialect) has its concentration of its speakers in Zaria and the neighbouring towns. Dauranci (Daura dialect) centres in and around Daura, Had'ejiyanci centres in and around Had'eja, Bausanci (Bauchi dialect) and Guddiranci (Guddiri dialect) are mainly spoken in Bauchi and Guddiri and the surrounding towns respectively. The divisions according to

Dogo (1977) are:

West Hausa
1. Sokoto dialect (Sakkwatanci).
2. Katsina dialect (Katsinanci) and
3. Daura and Gobir (Dauranci and Gobiranci).
In Niger Republic the Daura/Gobir cluster includes Dogondouchi and Kurfey (Filingúe) dialects.

East Hausa
1. Kano dialect (Kananci).
2. Had'eja dialect (Had'ejiyanci).
3. Zaria dialect (Zazzaganci)
4. Bauchi dialect (Bausanci and Guddiranci in Katagum)

As would be expected, within the two major divisions, the sub-dialects have their own idiosyncrasies distinguishing them from the other sub-dialects with which they have been grouped. Below are examples of cross-dialect correspondences between the two main divisions.

| A | East | West | |
|---|---|---|---|
| 1 | **d'aacii** | **d'waacii** | 'bitterness' |
| 2 | **d'aatàa** | **d'waatàa** | 'garden egg' |
| 3 | **d'àatànniyaa** | **d'wàatànnaa** | 'a type of grass' |

East /d'/: West /d'w/.

| B | East | West | |
|---|---|---|---|
| 1 | **tsiinii** | **tsìinii**<br>**c'ìinii**<br>**t'ìinii** | 'sharpness' |
| 2 | **Katsina** | **Katsina**<br>**Kat'ina**<br>**Kac'ina** | 'Katsina town' |
| 3 | **Tsiiga** | **Tsiiga**<br>**T'iiga**<br>**C'iiga** | 'Tsiga town' |

| | | | |
|---|---|---|---|
| 4 | **tseerèe** | **tseerèe**<br>**t'eerèe**<br>**c'eerèe** | 'escape' |
| 5 | **tsaamiyaa** | **tsaamiyaa**<br>**t'aamiyaa**<br>**c'aamiyaa** | 'tamarind' |
| 6 | **kitsèe** | **kitsèe**<br>**kit'èe**<br>**kic'èe** | 'fat' |

East /ts/: West /ts:t':c'/.

| C | East | West | |
|---|---|---|---|
| 1 | **k'ootàa** | **b'ootàa** | 'handle of a hoe' |
| 2 | **suk'ùt** | **sub'ùt** | 'suddenly' |

East /k'/: West /b'/.

Sources: Ahmed and Daura (1970:86), Dogo (1977), Zaria (1982), Abubakar (1983:33) and Skinner (1971:302).

## 1.4 Phonological Preliminaries.

Before the historical and experimental studies are presented a few words concerning the Hausa consonantal phonemes and their distribution will be in order.

### 1.4.1 Consonantal Chart.

Table 1.1 presents a chart of the consonantal phonemes of Hausa (East dialect).

| Manner of Articulation. | bilabial | | labio-dental | alveolar | | retroflex | palato-alveolar | | palatal | palatalized velar | | velar | | labialized velar | | glottal | palatalized glottal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plosive | | b | | t | d | | | | | ky | gy | k | g | kw | gw | ʔ | |
| glottalized | | b' | | | d' | | | | | k'y | | k' | | k'w | | | 'y |
| fricative | Φ | | f | s | z | | sh | | | | | | | | | h | |
| | | | fy | | | | | | | | | | | | | | |
| glottalized fricative | | | | | ts | | | | | | | | | | | | |
| affricate | | | | | | | ch | dz | | | | | | | | | |
| nasal | | m | | | n | | | | | | | | | | | | |
| tap/flap | | | | | r̃ | ɽ | | | | | | | | | | | |
| lateral | | | | | l | | | | | | | | | | | | |
| approximant | | | | | | | | | y | | | | | w | | | |

Table 1.1: Classification in Terms of Place and Manner of Articulation.

1.4.2 Vowel phonemes.

Hausa has five vowels, namely /i/, /e/, /a/, /o/, and /u/ plus two diphthongs, /ai/ and /au/. The five vowels can either be short or long, which brings the total number to ten. Table 1.2 presents the vowel phonemes.

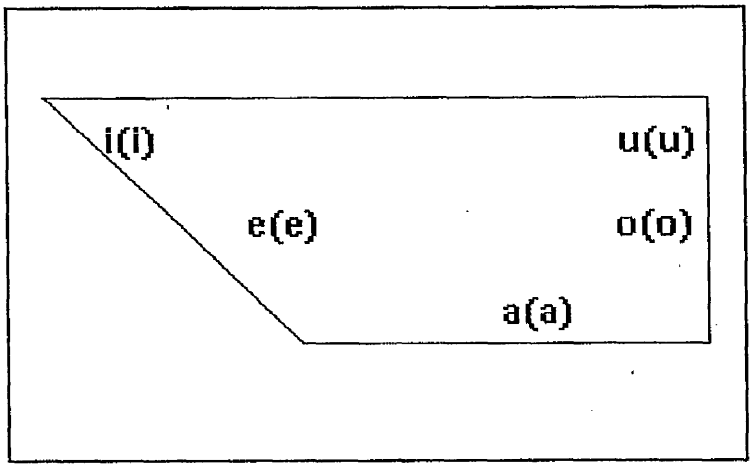



Table 1.2: Vowel Phonemes

1.4.3 Syllable Structure.

There are three syllable types in Hausa. They are:

| | | | |
|---|---|---|---|
| 1 | CV as in | **fita** | 'go out' |
| | | **d'aya** | 'one' |
| 2 | CVV as in | **kâi** | 'head' |
| | | **r̃iibàa** | 'profit' |
| | | **sauroo** | 'mosquito' |
| 3 | CVC as in | **nân** | 'here' |
| | | **har̃** | 'until' |
| | | **mântaa** | 'forget' |

1.4.4 Tone.

At the phonological level, Hausa has only two level tones - high (h) and low (l). In addition there is a complex falling tone analysed as sequences of two level tones - high+low. This tone occurs on heavy (CVC, CVV) syllables only. Only low (`) and falling (^) tones are marked in this study: high tone is left unmarked.

| | | | | |
|---|---|---|---|---|
| **ciki** | 'inside' | vs | **cikìi** | 'stomach' |
| **maasuu** | 'spears' | vs | **màasu** | 'possessors' |
| **faad'ii** | 'width' | vs | **faad'ì** | 'fall' |
| **sakàa** | 'put on' | vs | **sàak'oo** | 'message' |
| | | | | |
| **kâi** | 'head' | vs | **kai** | 'you (masc.sing.)' |
| **râi** | 'life' | vs | **sai** | 'until' |

1.4.5 The Glottalized Consonants.

In any description of Hausa phonology the following glottalic consonants are given /b'/, /d'/, /ts/, /k'/, /'y/ and /?/ (cf. Hoffmann and Schachter (1969) and Kraft and Kraft (1973)). The stops and affricates are often described as "implosives and ejectives". All the glottalic consonants can occur as geminates (cf. Table 1.3).

Table 1.3: Inventory of Hausa Glottalic Consonants

| | | | | | | |
|---|---|---|---|---|---|---|
| Single: | b' | d' | ts | k' | 'y | ? |
| Geminate: | b'b' | d'd' | tts | k'k' | 'y'y | ?? |

Examples (1-5) illustrate the phonemic contrast between glottalic and non-glottalic consonants:

1 /b'/ and /b/.

| | | | |
|---|---|---|---|
| **b'aatàa** | 'spoil' | **baatàa** | 'a line' |
| **kab'àa** | 'put to lips' | **kabàa** | 'young dum palm' |
| **zàab'aa** | 'choose' | **zàabii** | 'guinea fowl' |

2 /d'/ and /d/.

| | | | |
|---|---|---|---|
| **d'aamèe** | 'tighten belt' | **daamèe** | 'mix' |
| **faad'àa** | 'fall into' | **faadà** | 'emir's palace' |
| **d'akà** | 'in the hut' | **dakàa** | 'pound grain' |
| **d'aid'ai** | 'one by one' | **daidai** | 'correct' |

3 /k'/ and /k/.

| | | | |
|---|---|---|---|
| **bàak'ii** | 'guests' | **bàakii** | 'mouth' |
| **k'afàa** | 'foot, leg' | **kafàa** | 'establish' |
| **hak'àa** | 'dig' | **hakà** | 'thus' |

4 /ts/ and /s/.

| | | | |
|---|---|---|---|
| **tsarkii** | 'cleanliness' | **sarkii** | 'emir' |
| **tsaarèe** | 'arrange' | **saarèe** | 'slash' |
| **tsaurii** | 'hardness' | **saurii** | 'quickness' |

5 /'y/ and /y/.

| | | | |
|---|---|---|---|
| **'yaa** | 'daughter' | **yaa** | 'pronoun 3 sg masc' |
| **'yaa'yaa** | 'children' | **yàayaa** | 'gather grass' |

### 1.4.6 The Geminates.

Examples of contrasts between glottalic and non-glottalic geminates are given below (see examples 1-4). Also given are examples of geminate /'y/ and /z/ (example 5), lexical contrast between single and geminate consonants (example 6) and grammatical function of gemination (example 7).

1 /b'b'/ /bb/

| | | | |
|---|---|---|---|
| **b'ab'b'àkee** | 'uproot' | **babbàkee** | 'grill' |
| **tàb'ab'b'ee** | 'mad one, masc.' | **d'èebabbee** | 'taken completely' |

2 /d'd'/ and /dd/

| | | | |
|---|---|---|---|
| **d'ad'd'àfaa** | 'to accuse someone falsely' | **daddàfaa** | 'to cook many times' |

3 /tts/ and /ss/

| | | | |
|---|---|---|---|
| **màtsattsee** | 'squeezed (masc.)' | **masassabii** | 'harvesting tool' |

4 /k'k'/ and /kk/

| | | | |
|---|---|---|---|
| **sàak'ak'k'ee** | 'woven, masc.' | **sàkakkee** | 'loosened, masc.' |
| **sàak'ak'k'iyaa** | 'woven, (fem.)' | **cìkakkee** | 'the filled one masc.' |

5. Geminate Glottal Stop and Laryngealized Palatal Glide.

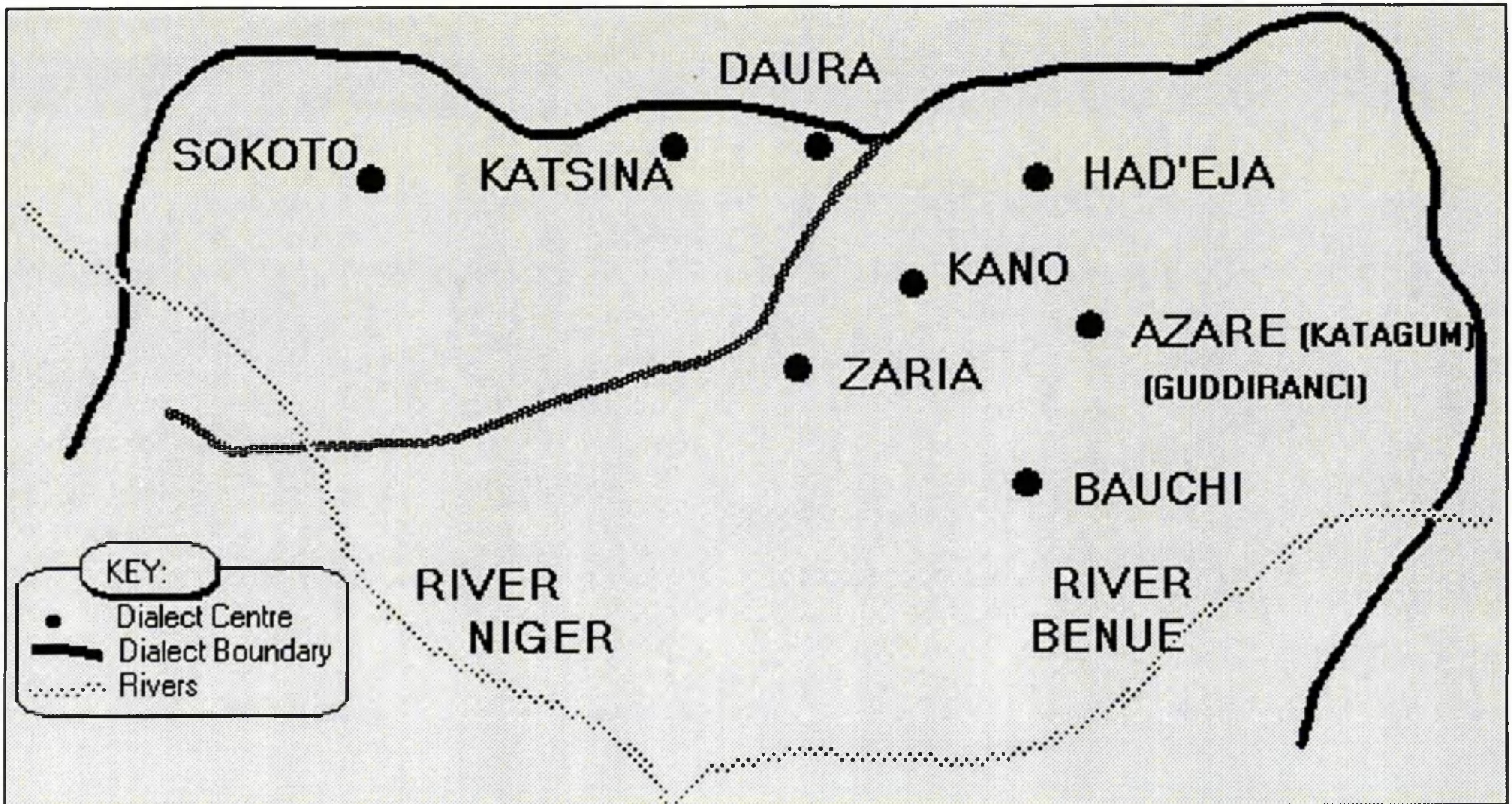
| | | | |
|---|---|---|---|
| (a) **a<u>??</u>àfaa** | 'throw (grain, rice) into mouth many times' | **a<u>??</u>àunaa** | 'buy something by measure many times' |
| (b) 'ya'y'yàawaa | 'small guinea corn stalks, bean plants, cut near harvest-time for fodder' | | |

6 Lexical Contrast between Single and Geminate Consonants.

| | | | |
|---|---|---|---|
| **kulè** | 'cat' | **kullèe** | 'lock' |
| **bàaba** | 'father' | **bàbba** | 'big' |
| **daabàa** | 'durbar' | **dabbàa** | 'animal' |
| **taalèe** | 'spread apart' | **tallee** | 'small soup pot' |
| **kwaalii** | 'carton' | **kwâllii** | 'antimony' |
| **laalèe** | 'shuffle cards' | **lallèe** | 'henna' |
| **hakìi** | 'grass' | **hakkìi** | 'due, right' |

7. Grammatical Function of Gemination.

| Singular | | Plural | |
|---|---|---|---|
| **damii** | 'bundle of corn' | **dâmmaa** | 'bundles of corn' |
| **saashèe** | 'department, section' | **sâssaa** | 'departments, sections' |
| **reeshèe** | 'branch' | **râssaa** | 'branches' |




Map 1.1: The major dialects of Hausa. Source: O'Brien (pers. comm).

# Chapter Two

Glottalic Consonants in Chadic.

## 2.1. Introduction

The presence of glottalic consonants in the phonological inventory of Hausa and related Chadic languages is a phenomenon well known to Chadicists. There are studies on the phonological correspondences, reconstructions of protoforms, comparative phonology etc. within the Chadic language family (cf. references below), but the history of the investigations has never been presented in great detail or in a very systematic way, although bibliographic surveys abound (cf. Hodge 1971 & 1983).[1] One serious question to be asked is, what is the historical origin of these presumably native Hausa phonemes (/b'/, /d'/, /ts/, /k'/ and /'y/) and to what do they correspond in related languages? Among recent treatments of this problem, one may mention several authors: Greenberg (1958), Newman and Ma (1966) (hereafter N/M), Newman (1977b) (hereafter NM), Skinner (1971), Parsons (1970), Jungraithmayr and Shimizu (1981) (hereafter JS), Jungraithmayr (1988) and Schuh (1982, 1984). The works of these scholars are the subject of this chapter.

In this chapter the Hausa glottalic phonemes /b'/, /d'/, /ts/, /k'/ and /'y/ have been singled out for special consideration. The first two, (/b'/ and /d'/) have been established for proto-Chadic (hereafter PC) and there are enough proofs for setting them up as protoforms /*b'/ and /*d'/. /ts/ and /k'/ are still controversial, and although they occur frequently in Hausa, the picture that emerges in the literature does not point to a single source for them. The reconstruction of /'y/ is still dubious due to lack of enough data or the questionable quality of the data.

The chapter also provides a general overview of the major treatments of the nature of PC glottalic consonants and presents them in a systematic way for easy reference. The generally accepted view is that there are probably four PC glottalic consonants, /*b'/ and /*d'/ plus either one or two others. The chapter also tries to show how modern Hausa glottalic consonants fit into the picture by surveying the distribution of the glottalic consonants within the Chadic family. Comparisons are therefore made of a number of native Hausa words that have /b'/, /d'/, /ts/, /k'/ and /'y/, with possible cognates from the West, Central, and East Chadic branches in order to determine, as far as the comparative evidence permits, the historical developments which might have given rise to these phonemes. The aim here is to show the important clues for the solution of the question of the origin of Chadic glottalic consonants.

For the sake of exposition, the different attempts to classify the Chadic family and the proposed proto-Chadic phonological inventory of reconstructions given by N/M (1966), NM (1977b), and JS (1981) are provided for comparison (cf. Tables 2.1-2.3).

Lexical forms which have glottalic consonants in present-day languages are presented and then compared with the corresponding PC items proposed by the different comparativists. The results of this show the similarities and differences between the different sets of hypothetical forms. In order to make the reconstructions easier to use for reference purposes, I have given the sources of the data. Moreover, languages which were not included in the earlier reconstructions (or have not received the full attention of Chadicists) have been included here. This is done in order to provide additional information, which I hope will shed more light on the matter and become useful in future reconstructions. Some such languages like Guruntum have only recently been described (cf. Jaggar 1988).

## 2.2. Problems of Reconstruction Within the Chadic Family

Although the reconstruction of /b'/ and /d'/ is quite straightforward, the position of /ts/, /k'/ and /'y/ cannot be determined satisfactorily for several reasons:

1 Sometimes, insufficient knowledge of sound changes makes cognate items very difficult to detect as correspondences may be inconsistent. Since there is little detailed study of the Central and East Chadic languages (compared to Hausa (West Chadic)), apart from the entries of word lists made by individual reseachers from their field notes, all that one can do is match Hausa words which have glottalic phonemes /b'/, /d'/, /ts/, /k'/ and /'y/ with corresponding phonemes in West, Central, and East Chadic, without describing the processes by which one changed into the other. For some discussion on sound changes in Hausa and other Chadic languages see Klingenheben (1928), Schuh (1972, 1974, 1976, 1978, 1982), and NM (1970, 1973, 1976, & 1977a).

2 Due to change in meaning (or extension in meaning) some words are sometimes put into different entries by field workers.

3 There is very little known about many of the phonologies of the languages within Chadic. There are many languages for which there is little or no data.

## 2.3 Basis of Comparing the Hausa Glottalic Phonemes

The comparison of the glottalized phonemes is approached through the comparative method, and on the following lines:

1 Comparisons of basic lexical items which have glottalized phonemes in them are made from a number of related Chadic languages regardless of whether they have previously been suggested or not.
2 Comparisons are not necessarily always made with words of identical meaning, but also with words which are semantically related.
3 Comparison of a sound is also based on the present-day distribution of its reflexes in the Chadic family. The hypothesis being made here is that the widespread distribution of a sound, if it is not due to borrowing, points to its possible existence in the ancestral language.
4 The absence of a reflex of a sound in some sub-branches of the Chadic family does not stop us from comparing its reflexes if such reflexes are found in some of the languages of other sub-branches.
5 No effort has been made to set up a theory about the origin of Chadic glottalic consonants. Rather, I have limited myself to providing cognate forms feasible at this present level of comparative study in support of what has been reconstructed so far.
6 Loan words which throw some light on the sources of a number of glottalic sounds have also been considered.

### 2.3.1 Notes on Conventions Used.

The conventions used in presenting the data are as follows:

1 Data entries with no source indicated are all from NM (1977b).
2 In the transcription of the data, I have modified the

original transcription in accordance with the conventions noted in Section 0.1

3 All protoforms from Lax (1986) are for West-Chadic A branch.

4 All protoforms from Schuh (1982) are for West-Chadic (A and B).

5 ** is used to represent some sort of phonetic entity in the "provisional reconstructions" of the West-A branch by Lax.

6 Each language is listed under the branch it belongs according to the classification in section 2.4.

7 The abbreviations WCA, WCB, CCA, CCB, ECA, ECB, MS, AA, NL and IE are introduced to represent, West Chadic A, West Chadic B, Central Chadic A, Central Chadic B, East Chadic A, East Chadic B, Masa, AfroAsiatic, Nilo-Saharan and Indo-European respectively.

## 2.4 Approaches to the Classification of Chadic.

> "The first task in the comparative study of African languages is to establish the closest and most coherent groupings on a scientific basis, i.e. groupings for which regular sound-correspondences and reconstructed common-forms may be postulated. Only when this has been done will it be possible to examine any remoter levels of relationship, on the basis of these immediate groupings" Dalby (1966:179).

It was not until Greenberg's (1950) publication in which he attempted a classification of Chadic languages that Chadic was recognised as forming a single linguistic unit. He classified the languages into nine groups as against Lukas' (1936) two-group classification "Chado-Hamitic" and "Mandara" groups (cf. Fig 2.1). Although Greenberg provided linguistic evidence to show the genetic relationship of the Chadic family of languages with the other members of the Afroasiatic phylum, he did not provide independent linguistic evidence to establish that the Chadic languages do indeed form a single linguistic unit, "his proof of the unity of the Chad family was thereby rendered weaker than it need have been" (N/M 1966:219).

The (1966) paper by N/M was the first major step taken to present a systematic comparative treatment of the phonological systems of the Chadic languages by making comparisons between the branches, despite the meagre information on some of the branches within the family. They set out "...to demonstrate conclusively that the Chad family as postulated by Greenberg does indeed constitute a valid linguistic unit" (N/M 1966:219).

Like Lukas (1936), they redefined the languages of this family into two major groups, which they called, "Plateau-Sahel" and "Biu-Mandara". They also posited subgroupings for the languages within this new classification (cf. Fig 2.2).

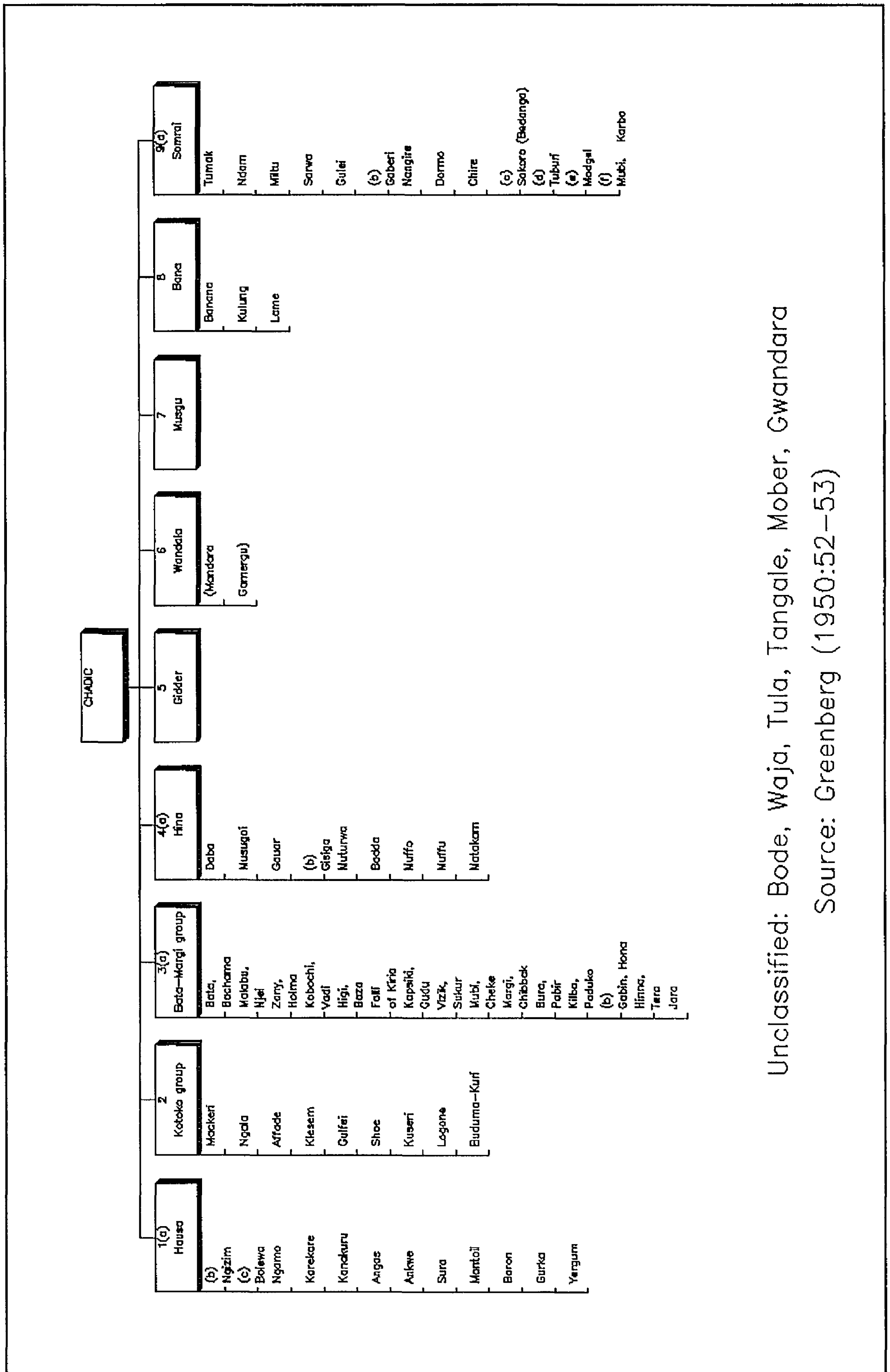



Figure 2.1: Chadic Classification According to Greenberg.

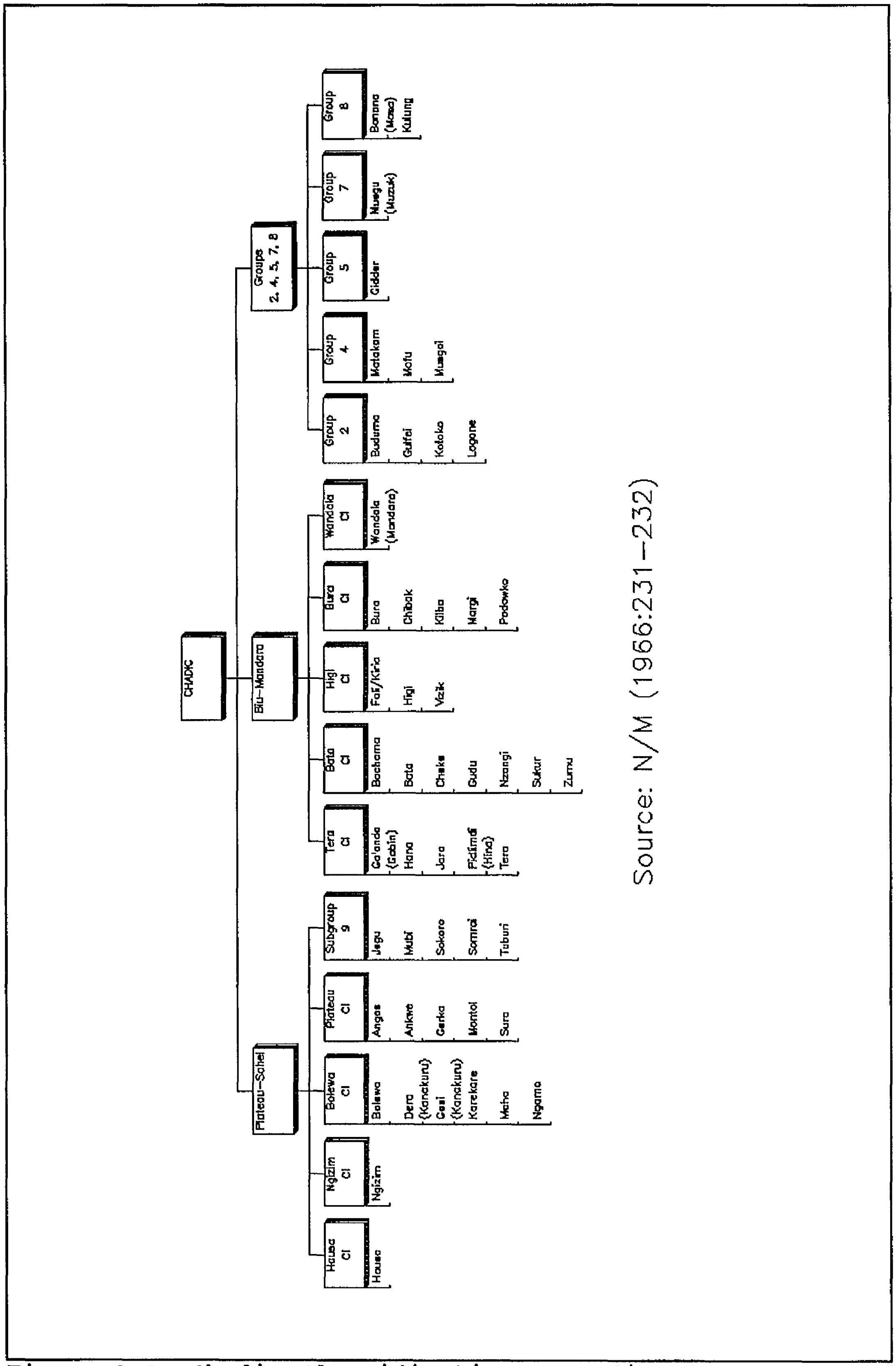



Figure 2.2: Chadic Classification According to Newman and Ma.

As an improvement over Greenberg (1950), N/M presented proofs that the Chadic family of languages does indeed constitute a valid linguistic unit by identifying cognates and positing reconstructions for 144 lexical items, based on regular sound correspondences between the branches they established.

N/M's article has made two major contributions to the study of Chadic phonology:

1 They set up a system for establishing sound correspondences using a number of languages;
2 They established good correspondences for proto-Chadic glottal phonemes /*b'/ and /*d'/.

However, despite their excellent account of Chadic protoforms, some general observations can be made on the correspondences proposed, which show that it had a limited scope. For instance,

1 No protoforms were set up for /ts/ and /'y/ (cf. Table 2.1).
2 No protoforms were set up for vowels.

With the continued increase of knowledge about the Chadic languages, NM (1977b) re-examined the lexical reconstructions postulated in N/M (1966) and made some improvements (cf. below). He also revised their (N/M 1966) classification of Chadic languages. The revised version consists of four branches, namely West, Biu-Mandara (Central), East and Masa. These groupings,

Table 2.1: N/M's (1966) Proto-Chadic Consonants. Source: N/M (1966:223)

| | | |
|---|---|---|
| p | t | k |
| b | d | g |
| b' | d' | - |
| f | s | - |
| - | z | - |
| m | n | - |
| w | r | - |
| - | l | - |

according to him demonstrated " ... greater and more precise internal structure (of Chadic) than provided in any previous classification" (NM (1977b:3) cf. Fig. 2.3).

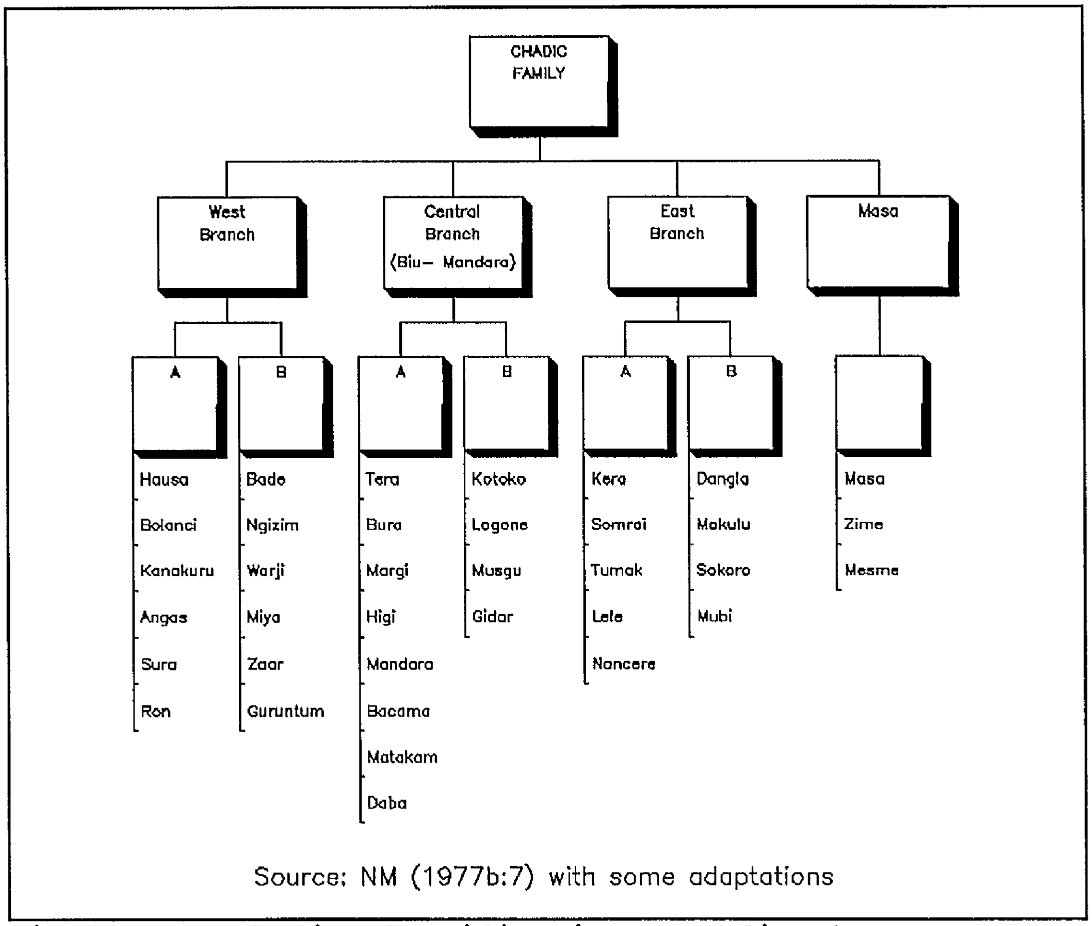



Figure 2.3: Chadic Classification According to Newman

NM (1977b) included an indexed classification of all Chadic languages (over 100) and dialects then known to him from the level of sub-group to major branch.[2] He also presented new reconstructions of the proto-Chadic phonological inventory and of 150 lexical items (cf. Table 2.2 for NM (1977b) PC consonantal inventory).

The reconstructed phonemic inventory includes for the first time palatalized and labialized consonants and vowels. For the consonants, a large number of sound laws are described leading from the PC to the modern reflexes in individual languages and language groups. The (1977b) article then became one of the best studies of a number of Chadic languages which contain glottalic consonants, and it is probably still our most informative source of reconstructed forms so far which is credible as well as being the most comprehensive. Almost all the reconstructed forms have reflexes in Hausa, although sometimes due to the problems of reconstruction listed above (cf. Section 2.2.), or simply due to the fact that the Hausa examples are well known, NM did not cite them.

As regards the glottalic consonants, NM (1977b) did not set up protoforms for all phonemes. He says simply that /*b'/ and /*d'/ plus a third one exist.

Table 2.2: NM's (1977b) Proto-Chadic Phonemes.
Source: NM (1977b:9)

| | | | | | |
|---|---|---|---|---|---|
| p | t | c | k | ky | kw |
| b | d | j | g | gy | gw |
| b' | d' | 'J | - | - | - |
| f | s | (sh) | x | xy | xw |
| | z | | | | |
| | S | | | | |
| m | n | | | | |
| | hl | | | | |
| | r | | | | |
| w | | y | | | |

## 2.5 The Implosives /b'/ and /d'/

In their (1966) article, N/M reconstructed /*b'/ and /*d'/ as PC phonemes saying,

> "the glottalized phonemes *b' and *d' are well established not just on the basis of the supporting examples but also because of the remarkable absence of counterexamples" (1966:223).[3]

However, N/M admitted the possible existence of another glottalized proto-phoneme in addition to the /*b'/ and /*d'/ already established. They tentatively listed this phoneme as /*'w/, some kind of glottalized velar (P:223). Like N/M (1966), NM's (1977b) paper also established /*b'/ and /*d'/. Similarly, Schuh (1982) and JS (1981) both postulated the existence of /*b'/ and /*d'/. Parsons (1970), however, proposed that /b'/ and /d'/ might be reflexes of "prenasalized phonemes" /*mb/ and /*nd/. He remarked:

> "The question then arises, do we postulate all four glottalized consonants in Hausa arising from pre-nasalized ones, i.e. /mb/, /nd/, /ng/, /nz/, or only /k'/ and /ts/? And, if all of them, then what has become of Proto-Chadic /b'/ and /d'/? Or, again, are some of the Hausa words with /b'/ and /d'/ derived from Proto-Chadic /mb/ and /nd/, and others from Proto-Chadic /b'/ and /d'/ ? In this last case one would expect some homonyms with /b'/ and /d'/, but I cannot think of any, unless it be among the various meanings of d'im-/d'um-, viz. 'beat', 'pile on', 'warm(th)', 'noise'" (Parsons 1970:281-282).

However, Parsons is alone in trying to relate the origin of the Hausa glottalic phonemes /b'/ and /d'/ to "prenasalized consonant phonemes."

## 2.6 The Ejectives /ts/ and /k'/

The ejectives are the areas of greatest controversy. In considering the history of the ejectives N/M (1966) reconstructed /*'w/ as a possible source of Chadic glottalized consonants other than /*b'/ and /*d'/. They remarked:

> "We believe that proto-Chadic probably also had some kind of glottalized velar (perhaps *'w) due to the fact that many present-day Chadic languages do have at least one other glottalized consonant in addition to b' and d'" (N/M 1966:223).

They therefore reconstructed /*'w/ as one of the sources of modern Hausa /k'/, listing the following example, 'bone' (No.127, p:241) *'W-s- Hs:**k'ashii**. Other supposed reflexes in Chadic are: Tr:**'gEtl**; Ngm:**'oso**; Sr:**'Jes**; Jg:**'eso**; Bc:**'ule**; Br:**'yetlu**; and Wd:**šeše**. Apart from this single example N/M did not provide any other support for their suggestion, due to insufficient evidence.

As an improvement on the (1966) article, NM (1977b) rejected their earlier hypothesis that /*'w/ was the third PC phoneme in addition to /*b'/ and /*d'/. Instead he reconstructed /*'J/ as the source of some instances of modern Hausa /k'/ (cf. Table 2.2 above for his PC phonemes). As NM says, "In some of its instances, Hausa k' is a reflex of this proto-phoneme, e.g. **k'ashii** 'bone' < ***'Jaşu**" (NM 1977b:14).

Furthermore, NM also considered /k'/ to have another source, a split of original /*k/ into /k/ and /k'/. In other words there are two separate sources for modern /k'/, one is /*'J/ and the other is /*k/ (NM 1977b:14).

NM (1977b:14) listed the following examples of (/k/ < *k; /k'/ < *k): Hs:**kai**; Kr:**koi** 'head'; Hs:**jik'a**; Kr:**yeke** 'become wet'. The conditioning factor for such a split he was not able to spell out. But in an earlier paper, NM (1973), he had tentatively suggested that "the major conditioning factor for the *k > k' change was the presence of a voiced consonant in the preceding or following syllable" adding that, "This hypothesis - which I still feel to be on the right track - awaits verification" (NM 1977b:14).

NM's claim that modern /k'/ developed from PC /*k/ is consistent with some evidence from Guruntum (West Chadic B). There is a regular correspondence between Hausa /k'/ and Guruntum /k/ in the following probable cognates.

| | | Hs. | Gr. | |
|---|---|---|---|---|
| Examples: | 'neck' | **k'eeyàa** | **kàaya** | (cf. JG. 1988: 186) |
| | 'dust' | **k'ùuraa** | **kudì** | (cf. JG. 1988: 184) |
| | 'strength' | **k'arfii** | **kwami** | (cf. JG. 1988: 188) |

Guruntum does not have a distinctive phoneme /k'/ (cf. Haruna (1981) and Jaggar (1988)).

While still considering words that contain /k'/, e.g. Hs:**k'udaa** 'fly(n)', one finds that the phoneme /k'/ has also been considered (although not categorically stated, but implied) as a reflex of /*d/ by NM. Consider the following examples: 'fly(n)' ***diwa**, Kk:**diyau**, Ng:**juw-ak**, Hs:**k'udaa** (AH), Gs:**jijuw-ed'**, Mg:**adway**, Dr:**diwo**, Sm:**dou**, Ms:**oro-na** (NM 1977b:26), Gr:**dìdau** (Jaggar 1988:184). The important point to note here is that NM has /k'/ as a reflex of either /*d/, /*'J/, or /*k/. In his discussion, NM did not treat /ts/.

Parsons (1970) (answered by NM (1971) cf. below for detailed discussion), arguing for the non-inclusion of Hausa as Chadic, presents some phonological arguments for his doubts, even though he has admitted that his knowledge of Chadic languages other than Hausa was second hand. He presents the following reasons for considering Hausa as unique.

1 The existence of /ts/ and /k'/ in Hausa but absence in other Chadic languages.

2 The absence of /ts/ and /k'/ in N/M (1966). According to Parsons, Hausa "..is a language which has an almost unnaturally tidy and symmetrical system of sound differentiation, distribution and utilization" (Parsons 1970:274).[4]

Parsons suggested that Hausa /k'/ and /ts/ might be reflexes of "prenasalized phonemes" /nk/, /ng/ and /ns/ or /nz/ respectively (Parsons 1970:281).

While agreeing with Parsons that the origin of the phonemes /ts/ and /k'/ is still a problem which remains unsolved in Chadic, NM says,

> "While I admit that like Parsons I have no ready answer to this question, I do not see how our ignorance can be adduced as evidence in support of his (Parsons') thesis that Hausa is not a Chadic language. The solution to the problem may have a bearing on the classification of Hausa but the mere existence of such a problem is not itself significant" (NM 1971:171).

There are additional problems with Parsons' claims:

1 Parsons did not provide sufficient evidence to support his claim that /k'/ and /ts/ derived from the prenasalized phonemes (/nk/, /ng/ and /ns/ or /nz/) respectively. He only cites the form **k'wai** 'egg' PC *(Ń)g-(r) (cf. N/M 1966:234) in support of his claim.

2 As noted in Skinner (1971) when Hausa borrowed words containing /NG/ from Kanuri (cf. Greenberg (1960) for a study of Kanuri loan words into Hausa), /NG/ did not become glottalized phoneme but rather acquired a

prothetic vowel preceeded by a glottal stop. Consider the following examples of borrowing from Kanuri into Hausa taken from Skinner (1971:301):

| | | | |
|---|---|---|---|
| Examples: | 'fine horse' | **ngErma** > | **'ingarmaa** |
| | 'behold!' | **ngo** > | **'ungoo** |
| | 'good/fine' | **ngEla** > | **'ingancii** |
| | 'ward' | **nguro** > | **'unguwaa** |
| | 'vulture' | **ngErmu** > | **'ùngùlu** (AH) |

Although borrowing of this kind might have taken place at some stage, this still does not strengthen the case of /NC/ > /C'/ (/C'/ = glottalized consonant; /NC/ = prenasalized consonant).

Other loan-word evidence, however, seems to support the hypothesis that Hausa glottalized consonants have come about as a result of the coalescence of a nasal segment plus plosive, i.e. /NC/ > /C'/. Consider the following examples of borrowing from West Atlantic languages into Hausa also cited by Skinner (1971:303), where he suspects the possibility that these forms are related:

| | | | | |
|---|---|---|---|---|
| | Vai | | Hausa | |
| 'groundnut' | **gyende** | > | **gyad'aa** | |
| | Wolof | | Hausa | |
| 'groundnut' | **ngerte** | > | **gyad'aa** | |
| | Mande | | Hausa | |
| 'hair' | **kunsigi** | > | **kits-** | 'to plait hair' |
| 'sweet thing' | **ma ndi** | > | **mad'ii**[5] | 'a sweet drink' |
| 'to take pleasure' | **da ndi** | > | **daad'ii** | 'pleasure' |

Skinner suggests that the loan words acquired glottalization when adopted into the Hausa language or else the feature might have been acquired later as a result of the loss of the /N/. Still, the coalescence hypothesis, Skinner admits, is debateable, from the point of view of what we know about Hausa clusters /-<u>nd</u>-/ and /-<u>nt</u>-/, for they are acceptable clusters in the present day language. For example, **dàndi** 'roaming about leading to a loose, carefree life' and **bàntee** 'loin-cloth'.

3 A further argument against Parsons' prenasalized phoneme theory is based on the observation that many other Chadic languages are found to have at least one other glottalized phoneme in their phonological inventory apart from /b'/ and /d'/ (cf. above). Thus, the overriding view today is that /ts/ and /k'/ could be related to some Chadic glottalized velar or palatal phoneme(s).

From a somewhat different view point, Skinner (1971) suggested that a good starting point from which to consider the history of Hausa /ts/ and /k'/ is the fairly large number of loan-words, mostly from Arabic that include glottalized consonants in Hausa (cf. Greenberg (1947) for detailed study of Arabic loans into Hausa). For example, Arabic (uvular) /q/ > Hausa /k'/ is fairly regular with /ḳ/ : /ʔ/ as a variant in some dialects, as is Arabic (alveolar emphatic) /ṭ/: Hausa /d'/ with /ts/ as a variant in some dialects (cf. below).

Skinner also cited examples of borrowing from Kanuri (Nilo-Saharan), Mande, Vai, Wolof, Fula (Niger-Congo) (cf. above), English and Arabic. Only a few examples from these languages will be given here.

He suggests that "there are signs that the glottal feature in loan words may represent traces of a number of elements in the donor language and come into existence in several ways" (p. 304), one of which is fusion of /ʔ/ plus consonant, cf. examples below.

Thus Skinner was the second scholar to propose a merger, though this is limited by him to the merging of two segments, one of them being /ʔ/. Consider the following examples given by Skinner (1971:302-303):

| | |
|---|---|
| 'fall in, collapse' | **rizb'-/rizb-** |
| 'to escape' | **sub'ut-/subt-** |
| 'fling down' | **yarb'-/yarf-** |
| 'pincers' | **hantsakii/hansakii** |
| 'to print' | Ar:**tabʔa** > Hs:**d'aab'aa** |
| 'affair, business' | Ar:**mas'ala** > Hs:**matsalaa** |
| 'post-office' | Eng:post-office > Hs:**fas'oofis/ fasa'oofis**, i.e. /st/ > /s'/ |
| 'crochet tray mat,' | Eng:antimacassar > Hs:**tumaak'asaa** |
| 'ankle-fetters' | Kn:**salga** Hs:**sark'aa** 'chain' Tb:**salka, selga** |
| 'adhere, stick' | Kn:**ligeri** Hs:**liik'-** Tb:**legere** |
| 'beseech, pray' | Kn:**logo-** Hs:**rook'-** |

On the other hand, Skinner feels that the picture that emerges does not point to a single source for /ts/ and /k'/ (cf. Skinner 1971:309). Furthermore, comparing Hausa /ts/ and /k'/ with some other Chadic languages, he found some evidence which, according to him, supports the idea that /k'/ (but not /ts/) may originally have come from PC /*k'/. This is because, says Skinner, /k'/ is found to occur more frequently in Hausa than /ts/ (cf. Skinner 1971:309). To illustrate how frequently /k'/ occurs in Hausa, he gives the following examples, (cf. p.308).

| | | | |
|---|---|---|---|
| 1 | 'black' | Hs:**bak'ii** | |
| | | Bd:**pElka** | |
| | | Bl:**bumm** | (? < ***bugum**) |
| 2 | 'stranger, guest' | Hs:**baak'oo** | |
| | | Ms:**markoi** | (? < **ma-rkoi**) |
| | | Lg:**maXoe** | (? < **ma-Xoe**) |
| | | Bd:**magrav** | (? < **ma-grav**) |
| | | Tr:**? rungi** | |
| | | ? rk > k' | |

Skinner added that:

> "On the other hand, comparison here with other Afroasiatic languages does lend some support to the idea that the etymon of the Hausa /k'/ was here a velar with an additional feature, rather than a cluster, comprising /?/ plus another phoneme" (p.307).

On the whole Skinner's article can be praised for providing evidence from both within and outside Chadic in the search for the origin of /ts/ and /k'/ in Hausa.

Table 2.3: JS's (1981) Proto-Chadic Phonemes
Source JS (1981:19-20)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| p | b' | b | mb | m | | | | w | |
| t | d' | d | nd | n | l | | r | | |
| (c) | ?y | (j) | (nj) | | | | | y | |
| k | k' | g | ng | | | (h) | | | (?) |
| | s1 | | | | | | | | |
| | s2 | | | s? | | z | | | |
| | s3 | | | | | | | | |
| | lz1 | | | | | lz | | | |
| | lz2 | | | | | | | | |

() not yet established

JS's (1981) study of Chadic Lexical Roots, gives a comprehensive representation of proto-Chadic glottalic sounds. It is the only study that reconstructs all five of the glottalic phonemes (/*b'/, /*d'/, /*ts/, /*k'/ and /*'y/ (cf. Table 2.3).

JS's approach to carrying out the reconstructions was

> "...determined entirely on the basis of the present-day distribution of the reflexes. Thus it is our (JS) working hypothesis that the Chadic-wide distribution of a root indicates its possible Proto-Chadic origin, if the wide distribution is not due to borrowing, and that we may thus reconstruct it at the Proto-Chadic level" (JS 1981:27).

Three levels of reconstruction, i.e. root, sub-root, and variants are set up and presented. For each lexical item they said, "there often exist for a given lexical item not only one, but often two or more widely distributed Proto-Chadic roots" (JS 1981:27). The reconstructed sets are given in order of the most widely used to least widely used with the branch and sub-branch noted, something which in the words of the authors "was neglected in earlier studies" (JS 1981:28). JS suggested that /*ts/ and /*k'/ are protoforms from which the modern /ts/ and /k'/ derive.

However, JS failed to give the actual forms in the language(s) on which the reconstructions were made. They also did not give the sound laws to account for the reflexes of /*k'/ and /*ts/ in modern Chadic languages. Another problem that may cast some doubt on the setting up of protoforms /*ts/ and /*k'/ is their limited distribution in modern Chadic languages apart from Hausa.

Schuh's (1982) work was limited to West Chadic.[6] Building on the earlier reconstructions of proto-Chadic forms by NM (1977b) and a few other sources and also his own field work notes, he made several suggestions of the possible sources of /ts/ and /k'/. Evidence from the comparative data he considered made him suggest that Hausa /ts/ and /k'/ have cognate forms in other West Chadic languages. Schuh provided a list of West Chadic etymologies as evidence pointing towards their existence in Proto-West Chadic. For example, he suggests that Hausa **tsayaa** and Bolanci **'yoruu-** 'to stand' come from an original root something like ***d'yar-**, (p. 9), i.e (Hs.ts:Bl.'y < *d'y). However Schuh in other cases also suggested that /ts/ and Bolanci /'y/ originate from /*'y/. Consider the following examples:

| | | | | |
|---|---|---|---|---|
| 'stand' | ***d'yar-** | Hs:**tsayaa**; | Bl:**'yoruu-**; | (p. 9) |
| 'fat' | ***k-'y-r** | Hs:**kitsee**; | Bl:**shid'or**; | |
| | | | My:**ha?ar**; | (p. 13) |
| 'urine' | ***f-'y-r** | Hs:**fitsarii**; | Bl:**'yofaa-bu?um**; | |
| | | | Ng:**v@d'au**; | (p. 13) |

| | | | | |
|---|---|---|---|---|
| 'guinea corn' | ***'y-l-** | Hs:**hatsii**; | Bl:**'yala.** | (p. 16) |

According to Schuh ha- (which is common in Hausa and West Chadic-B) is a prefix.

Schuh's reconstructions for proto-West Chadic suggest that /k'/ has five separate sources as either /*'y/, /*'w/, /*k/, /*'J/ and /*d /. See the following examples below:

| | | | | | |
|---|---|---|---|---|---|
| a | /*'y/ | 'weave' | ***sa'y-** | Hs:**saak'aa**<br>Bl:**sa'y'yuu-**<br>Ng:**caakau** | (cf. S. 1982:18). |
| | | 'be dry' | ***f-'y-** | Hs:**fak'oo**<br>Bl:**po'y'yuu-**<br>Ng:**w@d'u**<br>My:**ts@f@** | 'hard ground'<br><br><br>(cf. S. 1982:14):<br>/k'/ < /*'y/. |
| b | /*'w/ | 'dig' | ***'waf-** | Hs:**k'waafii**<br>Bl:**?oppuu-** | 'fill in where crops fail to germinate'<br>(cf. S. 1982:16):<br>/k'w/ < /*'w/. |
| c | /*k/ | 'calabash' | ***kul-** | Hs:**k'waryaa**<br>Bl:**kula** | |
| | | 'camel' | ***l-K-m** | Hs:**raak'umii**<br>Ng:**dl@gamau** | (cf. S. 1982:16):<br>/k'/ < /*k/. |
| d | /*'J/ | 'bone' | ***'Jaşu** | Hs:**k'ashii**<br>Bl:**?osoki**<br>My:**kusii**<br>Gr:**yiŋshi** | <br><br><br>(cf. JG. 1988:183);<br>(cf. S. 1982:12):<br>/k'/ < /*'J/. |
| e | /*d/ | 'fly (n)' | ***diwa** | Hs:**k'udaa**<br>Ng:**juwak**<br>My:**atiwii** | <br><br>(cf. S. 1982:19):<br>/k'/ < /*d/. |

A closer look at the data shows that the correspondences are so varied one from another that the sceptic might question the validity of some of the reconstructions. Nevertheless, the work is the first systematic comparative treatment of any one branch of the Chadic family (West Chadic branch) and shows the general picture as to the survival of proto-West Chadic sounds. It provides very good evidence demonstrating that even after a long period of separation considerable similarities still survive. Many more new reconstructions (more than the 150 items of NM 1977b) were made of items not normally found in the list of very frequent and common vocabulary.

## 2.7 The Glottalized Palatal /'y/

The glottalized palatal /'y/ was either neglected or left out as an open question by N/M (1966) and Parsons (1970). Skinner (1971) claims for Hausa that /'y/ < /?iy/ < /d'iy/ or as a result of the merging of /?/ and /y/. The examples quoted illustrate /'y/ in word initial position, except for those words that are borrowed or derived. Examples are 'daughter' **'yaa**, 'children' **'yaa'yaa**, 'freedom' **'yancii**, (cf. Skinner 1971:308). In the case of the Hausa words in which /'y/ occurred, for example /**'yaa**/ 'daughter', there is a dialect variation in the language, the alternate being /d'iy/. /'y/ in East Hausa alternates with /d'y/ in West Hausa. Skinner suggested that the word initial /'y/ could have occurred as a result of merging of /?/ with /y/ (cf. Skinner's claims for the origin of /k'/ and /ts/ above). Skinner was the first scholar to suggest the origin of this phoneme for Hausa.

Similarly JS (1981) also set up a protophoneme /*'y/. They suggested /'y/ < /*'y/ without providing any evidence for their claim nor did they provide any sound laws to account for the various reflexes of /*'y/ in modern Chadic languages. However, they warned that their reconstructions should be treated as tentative (JS 1981:19).

N/M (1966) left out /'y/ in their reconstruction. NM (1977b:10) suggested that /'y/ is a reflex of /*'J/ in some modern Chadic languages. He remarked:

> "This consonant (*'J) was probably a glottalized palatal stop, differing from *d' primarily by position rather than manner of articulation, and not an ejective like Hausa k' nor an approximant like Margi 'y. In present-day Chadic languages this proto-phoneme is variably realized as d'y, 'gy, 'g, k', 'w, 'y, ?, or ø." NM (1977:10).

The situation is further complicated by the fact that Hausa

/'y/ does not correspond to /'y/ in other West Chadic languages. Consider the following cognate sets: 'bone' (NM 1977b:23, No. 13), ***'Jasu** Sr:**d'yes**, Wr:**k'aasu-na**, Hs:**k'ashii**, Br:**d'yehlu**, Tr:**'gEhl**, Jg:**aso** and Nc:**ese**. Schuh (1982) suggests that /'y/ in Bole derives from /*'y/ in some cases. For example

| | | | |
|---|---|---|---|
| 'guinea-corn' | ***'y-l-** | Hs:**hatsii** | |
| | | Bl:**'yala** | (p. 16). |
| 'urine' | ***f-'y-r** | Hs:**fitsaarii** | |
| | | Bl:**'yofaa-bu?um** | (p. 13). |
| 'be dry' | ***f-'y-** | Hs:**fak'oo** | |
| | | Bl:**po'y'yuu-** | (p. 14). |

Writing on West Chadic vowel correspondences in a later paper, Schuh (1984) also reconstructed /*'w/ and /*'y/ for Proto-Bole-Tangale (West Chadic A) (cf. Fig. 3.3 for the names of other languages in this branch). He remarked:

> "Some words with initial vowels in modern Bole-Tangale languages must be reconstructed with initial glottalized semivowel + vowel sequences. Two semi-vowels, *'w and *'y, must be reconstructed for proto-Bole-Tangale. This reconstruction supports evidence from other Chadic languages that two glottalized consonants in addition to *b' and *d' must be reconstructed" (cf. Schuh 1984:193).

Although not enough well examplified cases of /*'w/ and /*'y/ have been found to establish clear correspondences, the examples found are given as follows:

2.7.1 Correspondences for Glottalized /'w/

| | | | | |
|---|---|---|---|---|
| 1 | 'smoke' | ***'walo** | Kr. | **(ùlìyau)/kwùlìyEw** (Kk) |
| | | | Bl. | **òllòki** |
| | | | Ng. | **?òlìyò** |
| | | | Kf. | **wèelè** |
| | | | Gal. | **wàala** |
| | | | Ger. | **wàya** |
| | | | Kk. | **jóló** |

| | | | | |
|---|---|---|---|---|
| 2 | 'bone' | *'was | Kr. | wàsu/òsu |
| | | | Kk. | kwasu |
| | | | Bl. | òsòki |
| | | | Ngm. | òso |
| | | | Kf. | wòoshanyi |
| | | | Gal. | wùshiy |
| | | | Ger. | wansÈnì |
| | | | Kk. | ween |
| 3 | 'metal' | *'wayEm | Kr. | 'wàyum/òyum |
| | | | Bl. | òyum |
| | | | Ngm. | òyù |
| | | | Kf. | wòyòmu |
| | | | Gal. | wee |
| | | | Ger. | wàimì |
| | | | Kk. | ayim |

Source: Schuh (1984:194, No. 52).

2.7.2 Correspondences for Glottalized /'y/

| | | | | |
|---|---|---|---|---|
| 1 | 'thing' | *'ya | Bl. | 'ya |
| | | | Ngm. | 'yà |
| 2. | 'stop' | *'yAru- | Kr. | yàaru- |
| | | | Bl. | 'yoru- |
| | | | Kk. | yìri |
| 3. | 'grind' | *'yasu | Kr. | 'yàsu- |
| | | | Bl. | òssu- |
| | | | Ger. | 'yàsÈ- |
| | | | Kk. | d'ee |
| 4. | 'submerge' | *'yimb/tu- | Kf. | d'imbu- |
| | | | Gal. | ìmb- |
| | | | Ger. | yìmtÈ- |
| | | | Kk. | yùmbure |
| 5. | 'pull' | *'yallu- | Bl. | d'yòllu |
| | | | Ngm. | ell- |

Source: Schuh (1984:194 No 54, 55)

## 2.8 Summary

In summary, most Chadicists now believe that there are four proto-glottalic consonant phonemes in Chadic namely /*b'/, /*d'/ plus two others. N/M (1966), NM (1977b), JS (1981) and Schuh (1982) (for West Chadic) all accept without debate that most modern /b'/ and /d'/ represent reflexes of PC phonemes /*b'/ and /*d'/. Parsons (1970) claimed (as his analysis suggests) that /b'/ and /d'/ (at least for Hausa) originate from *NC (i.e. prenasalized consonants). Skinner (1971) claimed that ʔ + C (i.e. glottal stop plus consonant) is the possible source of some instances of these consonants (a hypothesis already advanced by Illič-Svityč (1966)), and that borrowing is the source in other cases.

As regards the possible source for /k'/, the reconstructions for PC by N/M (1966) suggest /*'w/, NM (1977b) claimed /*'J/, /*d/ and /*k/, and JS (1981) reconstructed /*k'/. Parsons (1970) traced its origin from *NC (prenasalized consonant) either as /nk/ or /ng/. For Skinner (1971) it is ʔ + C (glottal stop plus a consonant) for Hausa. Finally, Schuh (1982) suggests that /k'/ (for West Chadic) originates from five possible sources, either /*'w/, /*'J/, /*'y/, /*k/ or /*d/.

As regards /ts/, N/M (1966) and NM (1977b) did not provide any discussion on it. Parsons (1970) considers Hausa /ts/ to have come from an original prenasalized consonant - either /ns/ or /nz/. Skinner (1971) claimed that /ts/ comes from a merger of glottal stop plus following consonant. JS (1981) reconstructs /*ts/ as the source of /ts/, and Schuh (1982) tentatively reconstructs /*d'y/ and /*'y/ for West Chadic as the possible source of some instances of Hausa /ts/ and Bolanci /'y/.

As regards /'y/, Skinner claimed that it has its source from /*d'iy/ > /'iy/ > /'y/ or through the direct merging of /?+C/. NM (1977b) suggests /*'J/ as one of the sources of /'y/, while JS reconstructed /*'y/ > /'y/. Schuh (1984) claimed that West Chadic-A /'y/ < /*'y/ and /'w/ < /*'w/ for Proto-West Chadic (sub-branch A). N/M (1966) and Parsons (1970) are the only authors who did not consider /'y/ in their reconstructions.

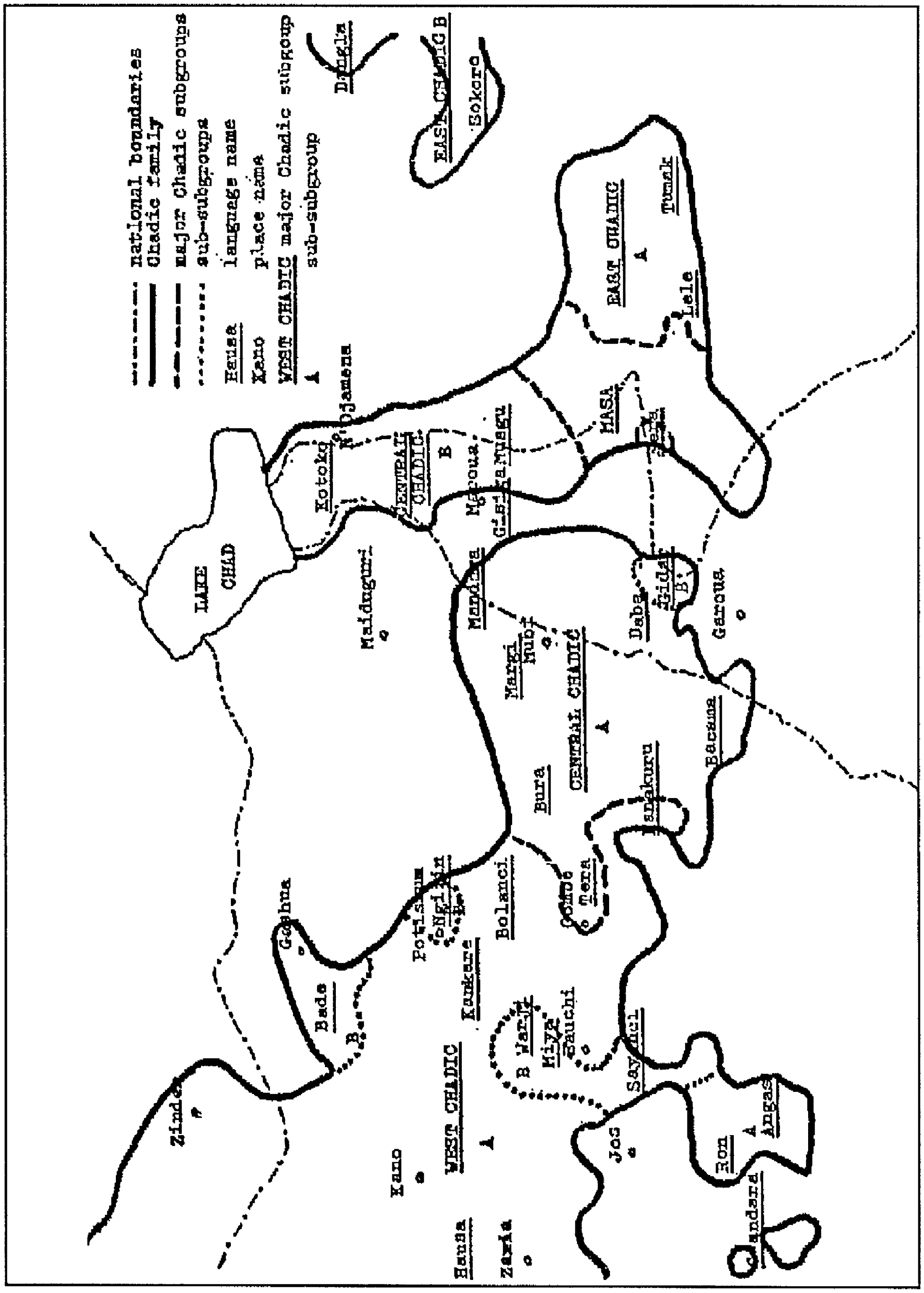
## 2.9 Table of Languages: Numbering System and Language Abbreviations

| | | | | | |
|---|---|---|---|---|---|
| 1 | West Chadic-A: (WCA) | Hs. | Hausa | Bl. | Bolanci |
| | | *Dr. | Dera | *Kk. | Kanakuru |
| | | Ang. | Angas | Sr. | Sura |
| | | Rn. | Ron | Kf. | Kirfi |
| | | Df. | Daffo (dialect of Ron) | | |
| | | Pr. | Pero | Sh. | Sha |
| | | Ank. | Ankwe | Kfr. | Kofyar |
| | | Kr. | Karekare | Gal. | Galambu |
| | | Ger. | Gera | | |
| | West Chadic-B: (WCB) | Bd. | Bade | Ng. | Ngizim |
| | | Wr. | Warji | My. | Miya |
| | | Zr. | Zaar | Pa. | Pa'a |
| | | Gr. | Guruntum | Ngm. | Ngamo |
| 2 | Central Chadic-A: (CCA) | Tr. | Tera | Hn. | Hona |
| | | Br. | Bura | Mg. | Margi |
| | | Hg. | Higi | Bc. | Bacama (Bata) |
| | | Md. | Mandara | (Wd. | Wandala) |
| | | Mt. | Matakam | Gs. | Gisiga |
| | | Db. | Daba | Pd. | Paduko |
| | | Mf. | Mofu | Gd. | Ga'anda |
| | Central Chadic-B: (CCB) | Kt. | Kotoko | Lg. | Logone |
| | | Msg. | Musgu | Gdr. | Gidar |
| | | Af. | Afade (dialect of Kotoko) | | |
| | | Bm. | Buduma | | |
| 3 | East Chadic-A: (ECA) | Ke. | Kera | Sm. | Somrai |
| | | Nc. | Nancere | Tm. | Tumak |
| | East Chadic-B: (ECB) | Dg. | Dangla | Mk. | Mokulu |
| | | Jg. | Jegu | So. | Sokoro |
| | | Mub. | Mubi | Mm. | Migama |
| | | +By. | Bidiya | | |
| 4. | Masa: (MS) | Ms. | Masa | Zm. | Zime |
| | | Mb. | Marba | | |
| 5 | Afroasiatic: (AA) | Ar. | Arabic | | |
| 6 | Indo-European: (IE) | Eng. | English | | |
| 7 | Nilo-Saharan: (NL) | Kn. | Kanuri | Tb. | Tubu |

* Same language. + NM 1977b spelled it as Bidiyo

Source: NM (1977b) with some adaptations.

The accompanying map 2.1 shows the location of some of the languages.




Source: Schuh (1982:4).

## 2.9.1. Sources of Data for Comparative List

In order to make the comparison easier to use for reference purposes, I have tried where possible to give more than one example of cognates or near cognates. In citing the examples, I have taken advantage of the insights and knowledge acquired and the records established from earlier isolated studies. I have depended on the works of: Hodge (1968), Greenberg (1958, 1965 & 1963 (3rd ed. 1970)), N/M (1966), NM (1964, 1977b), Hoffmann (1963, 1970, and 1971), Parsons (1970), JS (1981), Jungraithmayr (1988), Kraft (1981), Skinner (1971, 1977), Schuh (1982, 1984), Jaggar (1988), Gregersen (1967), Ladefoged (1968), Lax (1986) and Haruna (field notes: data collected through personal interviews of native speakers of some of the languages cited).

Author Abbreviation:

N/M: Newman and Ma (1966)
NM: Newman (1964, 1977b)
KR: Kraft (1981)
JG: Jaggar (1988)
JS: Jungraithmayr and Shimizu (1981)
S: Schuh (1982, 1984)
SK: Skinner (1971)
LD: Ladefoged (1968)
GR: Greenberg (1970)
AH: Haruna (field notes)
L : Lax (1986)
HF: Hoffmann (1963)
J: Jungraithmayr (1981; 1988)

## 2.10 Hausa and Chadic Lexicon

Turning now to some Chadic basic words in which the glottalized consonants occur, and quoting examples from the four branches of the Chadic family, as far as possible for each word, we have the following.

## 2.11 Comparative Wordlist for /b'/.

| | | | | |
|---|---|---|---|---|
| 1 | 'break' | | *b'ahlE | (cf. NM. 1977b:23, No. 15) |
| | | | *b'- ()l- | (cf. N/M. 1966:232, No. 7) |
| | Bl.(WCA) | b'olu | | |
| | Hs.(WCA) | b'alle | | |
| | Pa.(WCB) | b'ahlu | | |
| | Msg.(CCB) | b'El | | |
| | Mf.(CCA) | b'Ehl- | | |
| | Tr.(CCA) | b'axla | | (cf. N/M. 1966:232, No. 7) |
| | Bc.(CCA) | b'ia | | (cf. N/M. 1966:232, No. 7) |
| | Mg.(CCA) | b'atsEri | | (cf. HF.1963:140) |
| 2 | 'hit' | | *hlEb'E | (cf. NM. 1977b:28, No. 68) |
| | Pr.(WCA) | lovo | | |
| | Tr.(CCA) | hlab'E | | |
| | Msg.(CCB) | hlEb'- | | |
| | Tm.(ECB) | lEb | | |
| | Ke.(ECA) | laa | | |
| 3 | 'suck' | | *sEb'E | (cf. NM. 1977b:32, No. 125) |
| | | | *smb (-d') | (cf. JS. 1981:255) |
| | Bc.(CCA) | sEb'E | | |
| | Mf.(CCA) | asEb'- | | |
| | Mk.(ECB) | sib'- | | |
| | Ke.(ECA) | sob'e | | |
| | Zm.(MS) | sob'o | | |
| | Kt.(CCB) | s'afE | | |
| | Gr.(WCB) | b'ub'i | | (cf. Jg. 1988:188) |
| 4 | 'tie' | | **d'Vb'(-V) | (cf. L. 1986:102, No. 187) |
| | | | *g-n- | (cf. N/M. 1966:242, No. 142) |
| | Ang.(WCA) | b'at | | (cf. L. 1986:102, No. 187) |
| | Dr.(WCA) | d'ob'e | | (cf. L. 1986:102, No. 187) |
| | Kr.(WCA) | weni | | (cf. N/M. 1966:242, No. 142) |
| | Mub.(ECB) | ewen | | (cf. N/M. 1966:242, No. 142) |
| | Tr.(CCA) | gEnE | | (cf. N/M. 1966:242, No. 142) |
| | Hs.(WCA) | d'aure | | (cf. L. 1986:102, No. 187) |
| 5 | 'horn' | | **b'YIVm | (cf. L. 1986:104, No. 87) |
| | | | *mk (a) (t-;-m) | (cf. JS. 1981:142) |
| | Kr.(WCA) | belEm | | (cf. L. 1986:104, No. 87) |
| | Dr.(WCA) | b'ili | | (cf. L. 1986:104, No. 87) |

| | | | | |
|---|---|---|---|---|
| 6 | 'wash something' | *b-n- | | (cf. N/M. 1966:240, No. 115) |
| | | *c-b'E | | (cf. NM. 1977b:33, NO. 141) |
| | | *bn | | (cf. JS. 1981:282) |
| | Kk.(WCA) | job'e | | |
| | Zr.(WCB) | tsop | | |
| | Tr.(CCA) | cib'E | | |
| | Hg.(CCA) | yab'e | | |
| | Mub.(ECB) | cuubi | | |
| | Bl.(WCA) | bina | | (cf. N/M. 1966:240, No. 115) |
| | Ang.(WCA) | vwan | | (cf. N/M. 1966:240, No. 115) |
| | Br.(CCA) | pEra | | (cf. N/M. 1966:240, No. 115) |
| | Tr.(CCA) | vEnE | | (cf. N/M. 1966:240, No. 115) |
| | Bd.(WCB) | beno | | (cf. N/M. 1966:240, No. 115) |
| | Mt.(CCA) | pen | | (cf. N/M. 1966:240, No. 115) |
| | Msg.(CCB) | pay̧ | | (cf. N/M. 1966:240, No. 115) |
| 7 | 'mud (for building)' | | *t-b'- | (cf. N/M. 1966:237, No. 69) |
| | | *tab'- | | (cf. NM. 1977b:29, No. 89) |
| | Hs.(WCA) | tab'oo | | (cf. N/M 1966:237, No. 69) |
| | Bl.(WCA) | teb'b'i | | |
| | Ng.(WCB) | tab'o | | |
| | Kt.(CCB) | ndab'e | | |
| | Bc.(CCA) | sEb'we | | |
| | Tm.(ECB) | dubo | | |
| | Br.(CCA) | mEb'u | | (cf. KR. 1981:53) |
| | Tr.(CCA) | dàxb'à | | (cf. NM. 1964:41, No. 179) |
| | Hn.(CCA) | tab'E | | (cf. N/M. 1966:237, No. 69) |
| | Bc.(CCA) | čob'e | | (cf. N/M. 1966:237, No. 69) |

## 2.12 Comparative Wordlist for /d'/

| | | | | |
|---|---|---|---|---|
| 1 | 'four' | | ***f-d'-** | (cf. N/M. 1966:235, No. 38) |
| | | | ***fwad'E** | (cf. NM. 1977b:26, No.54) |
| | | | ****fVd'u** | (cf. L. 1986:100, No. 68) |
| | | | ***-pd' (m-;-w/y)** (11 ?) | (cf. JS. 1981:113) |
| | Ke. (ECA) | **waad'e** | | |
| | Bl. (WCA) | **pod'd'o** | | |
| | Wr. (WCB) | **fEd'i** | | |
| | Hs. (WCA) | **hud'u** | | (AH) |
| | Ng. (WCB) | **f@d'u** | | (cf. S. 1982:12) |
| | Msg. (CCB) | **fwadE** | | |
| | Mb. (ECB) | **fad'a** | | |
| | Sh. (WCA) | **fud'** | | (cf. L. 1986:100, No. 68) |
| | Kr. (WCB) | **fed'u** | | (cf. L. 1986:100, No. 68) |
| | Bl. (WCA) | **pod'd'o** | | (cf. S. 1982:12) |
| | Kk. (WCA) | **parau** | | (cf. S. 1982:12) |
| | Ng. (WCB) | **fud'o** | | (cf. N/M. 1966:235, No. 38) |
| | Bl. (WCA) | **fod'o** | | (cf. N/M. 1966:235, No. 38) |
| | Msg. (CCB) | **pudu** | | (cf. N/M. 1966:235, No. 38) |
| 2 | 'python' | | ***mEd'E** | (cf. NM. 1977b:30, No.100) |
| | Hs. (WCA) | **muud'uwaa** | | |
| | Bl. (WCA) | **mid'i** | | |
| | Gd. (CCA) | **myEd'-En** | | |
| | Kt. (CCB) | **mud'E** | | |
| 3 | 'night' | | ***bEd'i** | (cf. NM. 1977b:29, No. 92) |
| | | | ***-bd'- (t-,m-,-k; -m,-k)** | (cf. JS. 1981:194) |
| | | | ****bVd'i** | (cf. L. 1986:119, No. 121) (cf. also S. 1982:20) |
| | | | ***b'ed'i** | (cf. L. 1986:119, No. 121) |
| | Bl. (WCA) | **bod'i** | | |
| | Bd. (WCB) | **Egveed'-En** | | |
| | Db. (CCA) | **vud'u** | | |
| | Lg. (CCB) | **vad'e** | | |
| | Kr. (WCA) | **b'èed'ì** | | (cf. L. 1986:119, No.121) |
| | Dr. (WCA) | **birì** | | (cf. L. 1986:119, No.121) |
| 4 | 'say' | | ***p-r-** | (cf. N/M 1966: 238, No. 88) |
| | | | ***p-d'E/*p-rE** | (cf. NM. 1977b:31, No. 109) |
| | Hs. (WCA) | **fad'ii** | | |
| | Kr. (WCA) | **d'afu** | | |
| | Br. (CCA) | **pEl** | | |
| | Gdr. (CCB) | **pel** | | |
| | Bl. (WCA) | **poru** | | |

| | | | | |
|---|---|---|---|---|
| 5 | 'this, that, the' | | *d'- | (cf. NM. 1977b:33, No. 131) |
| | Hs. (WCA) | d'i-n | | |
| | Sr. (WCA) | d'i | | |
| | Gd. (CCB) | d'i, d'a | | |
| | Msg. (CCB) | d'a | | |
| | Dg. (ECB) | ed'e | 'here' | |
| | Tm. (ECB) | d'E | | |

| | | | | |
|---|---|---|---|---|
| 6 | 'left (side)' | *g-d'- | | (cf. NM. 1977b:28, No. 80) |
| | Ger. (WCA) | gyad'a | | |
| | Wr. (WCB) | gad'i | | |
| | Tr. (CCA) | gEd'au | | |
| | Bc. (CCA) | lyegd'e | | |

| | | | | |
|---|---|---|---|---|
| 7 | 'go away' | *d-n- | | (cf. N/M. 1966:235, No. 43) |
| | | *d'E | | (cf. NM. 1977b:27, No. 59) |
| | | **taf(-V) | | (cf. L. 1986:114, No. 72) |
| | Ng. (WCB) | d'e-tu | 'come' | |
| | Tr. (CCA) | d'E | | |
| | Mg. (CCA) | d'u | 'migrate' | |
| | Dg. (ECB) | aad'e | 'follow' | |
| | Kr. (WCA) | d'ee | | |
| | Bl. (WCA) | dina | | (cf. N/M. 1966:235, No. 43) |
| | Bc. (CCA) | da | | (cf. N/M. 1966:235, No. 43) |
| | Kt. (CCB) | deni | | (cf. N/M. 1966:235, No. 43) |

| | | | | |
|---|---|---|---|---|
| 8 | 'five' | *bad'E | | (cf. NM. 1977b:26, No. 50) |
| | | **bVd' | | (cf. L. 1986:113, No. 64) |
| | | *bd'y Lz (m-;-m) | | (cf. JS. 1981:108) |
| | Kr. (WCA) | baad'u | | |
| | Ng. (WCB) | vaad' | | |
| | Dr. (WCA) | bEEd'y | | |
| | Ke. (ECA) | wiid'iw | | |
| | Dr. (WCA) | baàt | | (cf. L. 1986:113, No. 64) |
| | Ang. (WCA) | pèt | | (cf. L. 1986:113, No. 64) |

| | | | | |
|---|---|---|---|---|
| 9 | 'breast, milk' | *w-d'- | | (cf. N/M. 1966:233, No. 9) |
| | | *wEd'i | | (cf. NM. 1977b:23, No. 18) |
| | | **yWd'i | | (cf. L. 1986:109, No. 24) |
| | | *wd' | | (cf. JS 1981:53) |
| | Kf. (WCA) | wud'i | | |
| | Sr. (WCA) | wur | | |
| | Tr. (CCA) | wud'i | | |
| | Bc. (CCA) | wad'in-tE | | |
| | Mk. (ECB) | ud'u | | |
| | So. (ECB) | wat | | |
| | Gr. (WCB) | wùru | | (cf. Jg. 1988:183) |
| | Kr. (WCA) | yàd'i | | (cf. L. 1986:109, No. 24) |
| | Ngm. (WCB) | wod'i | | (cf. N/M. 1966:233, No. 9) |
| | Zm. (MS) | watsu | | (cf. N/M. 1966:233, No. 9) |

| | | | | |
|---|---|---|---|---|
| 10 | 'bitter' | | *d'-t- | (cf. NM. 1977bb:22, No. 9) |
| | | | *d'-- | (cf. JS 1981:43) |
| | Hs.(WCA) | d'aacii | | |
| | Kfr.(WCA) | d'eet | | |
| | Tr.(CCA) | dyot | | |
| | Lg.(CCB) | uX-d'ata | 'gall' | |
| | Dr.(WCA) | d'yuutu | | |
| | Mg.(CCA) | d'àd'àhù | | (cf. HF. 1963:23) |
| | Mg.(CCA) | ?dà?dàhŵ | | (cf. LD. 1968:65) |
| 11 | 'swallow' | | **d'al(-V) | (cf. L. 1986:100, No. 177) |
| | | | *sd'k(l) ? | (cf. JS. 1981:258) |
| | Hs.(WCA) | hàd'iyàa | | (AH) |
| | Tr.(CCA) | d'Eka(ra) | | (cf.NM 1964:47, No. 427) |
| | Sh.(WCA) | dul | | (cf. L. 1986:100, No. 177) |
| | Ang.(WCA) | d'al | | (cf. L. 1986:100, No. 177) |
| | Kr.(WCA) | d'al-u | | (cf. L. 1986:100, No. 177) |
| | Dr.(WCA) | d'El-i | | (cf. L. 1986:100, No. 177) |
| 12 | 'cook' | | *da | (cf. NM. 1977b:24, No. 28) |
| | | | **dVnk(-V) | (cf. L. 1986:110, No. 37) |
| | Gd.(CCA) | da | | |
| | Lg.(CCB) | d- | | |
| | Msg.(CCA) | da | | |
| | Hs.(WCA) | dafàa | | (AH) |
| | Sh.(WCA) | dyèn | | (cf. L. 1986:110, No. 37) |
| | Dr.(WCA) | d'ìnge | | (cf. L. 1986:110, No. 37) |
| | Kr.(WCA) | d'ùnku- | | (cf. L. 1986:110, No. 37) |
| | | | | (cf. S. 1978:84) |
| 13 | 'millet' | | **mVd'o | (cf. L. 1986:104, No. 111) |
| | Kr.(WCA) | mard'o | | (cf. L. 1986:104, No. 111) |
| | Dr.(WCA) | mod'o | | (cf. L. 1986:104, No. 111) |
| 14 | 'sew' | | **dad'(-V) | (cf. L. 1986:122, No. 153) |
| | | | *zg | (cf. JS 1981:224) |
| | Hs.(WCA) | d'inkàa | | (AH) |
| | Sh.(WCA) | dumo | | (cf. L. 1986:122, No. 153) |
| | Ang.(WCA) | tèn | | (cf. L. 1986:122, No. 153) |
| | Dr.(WCA) | dad'e | | (cf. L. 1986:122, No. 153) |
| | Kr.(WCA) | dànd'u- | | (cf. L. 1986:122, No. 153) |
| | | | | (cf. S. 1978:84) |

15 'groundnuts' ***d'Vbero** (cf. L. 1986:114, No. 77)

| | | |
|---|---|---|
| Hs.(WCA) | **gyàd'aa** | (AH) |
| Sh.(WCA) | **jukùr** | (cf. L. 1986:114, No. 77) |
| Kr.(WCA) | **d'Ebero** | (cf. L. 1986:114, No. 77) |
| Dr.(WCA) | **d'eenò** | (cf. L. 1986:114, No. 77) |
| Tr.(CCA) | **wàdà** | (cf. NM. 1964:43, No. 290) |

16 'lift' ?

| | | |
|---|---|---|
| Hs.(WCA) | **d'aukàa** | (AH) |
| Ang.(WCA) | **d'àp** | (cf. L. 1986:117, No. 104) |
| Sh.(WCA) | **tEk** | (cf. L. 1986:117, No. 104) |
| Kr.(WCA) | **?asù** | (cf. L. 1986:117, No. 104) |
| Dr.(WCA) | **gErè** | (cf. L. 1986:117, No. 104) |

17 'one' ?

| | | |
|---|---|---|
| Hs.(WCA) | **d'aya** | (AH) |
| Kr.(WCA) | **wàdi** | (cf. L. 1986:120, No. 127) |
| Dr.(WCA) | **d'umoi** | (cf. L. 1986:120, No. 127) |
| Wr.(WCB) | **d'ook** | (AH) |
| Tr.(CCA) | **dà** | (cf. NM. 1964:36, No. 1) |

## 2.13 Comparative Wordlist for /k'/

1 'lightning' (?)

| | | | |
|---|---|---|---|
| Hs.(WCA) | **wàlk'iyaa** | | (AH) |
| Bl.(WCA) | **mik'ile** | | (cf. Kr. 1981:84) |

2 'egg'

| | | | |
|---|---|---|---|
| | | ***(Ǹ)g-(r)** | (cf. N/M. 1966:234, No. 26) |
| | | ***aṣi** | (cf. NM.1977b:25, No. 42) |
| | | ****Y̆s** | (cf. L. 1986:112, No. 52) |
| | | ***-lz- (k-, t-; -k, -r)** | (cf. JS 1981:94) |
| Pa.(WCB) | **iji** | | |
| Hs.(WCA) | **k'wai** | | (cf. L. 1986:112, No.52) |
| Pd.(CCA) | **hlihlya** | | |
| Mg.(CCA) | **ehle** | | |
| Ms.(MS) | **asi-na** | | |
| Ngm.(WCB) | **?yinsa** | | (cf. Kr. 1981:91) |
| Sh.(WCA) | **?ahob'ò** | | (cf. L. 1986:112, No. 52) |
| Ang.(WCA) | **ès** | | (cf. L. 1986:112, No. 52) |
| Kr.(WCA) | **?insà** | | (cf. L. 1986:112, No. 52) |
| Dr.(WCA) | **b'iya-yaab'è** | | (cf. L. 1986:112, No. 52) |

3 'weave'

| | | | |
|---|---|---|---|
| | | ***sa'y-** | (cf. S. 1982:18) |
| | | ****sak (-V)** | (cf. L. 1986:127, No. 204) |
| Hs.(WCA) | **saak'aa** | | (cf. S. 1982:18) |
| Bl.(WCA) | **sa'y'yuu-** | | (cf. S. 1982:18) |
| Ngm.(WCB) | **sa?ya** | | (cf. Kr. 1981:91) |
| Mg.(CCA) | **tsari** | | (cf. HF. 1963:142) |
| Ang.(WCA) | **sak** | | (cf. L. 1986:127, No. 204) |
| Kr.(WCA) | **càaku-** | | (cf. L. 1986:127, No. 204) |
| Ms.(MS) | **sasaka** | | (cf. Gr. 1970:63) |
| Ng.(WCB) | **caakau** | | (cf. S. 1982:18) |

4 'bone'

| | | | |
|---|---|---|---|
| | | ***'W-s-** | (cf. N/M. 1966:241, No. 127) |
| | | ***'JaSu** | (cf. NM. 1977b:23, No. 13) (cf. also S. 1982:12) |
| | | ****kYs** | (cf. L. 1986:109, No. 20) |
| | | ***k's$_3$ (-n, -k)** | (cf. JS. 1981:49) |
| Hs.(WCA) | **k'àshii** | | (AH) |
| Gr.(WCB) | **yiɣshì** | | (cf. Jg. 1988:183) |
| Wr.(WCB) | **k'aasu-na** | | |
| Sr.(WCA) | **d'yes, d'iyEs** | | (cf. J. 1988:67) |
| Br.(CCA) | **d'yehlu** | | (cf. J. 1988:67) |
| My.(WCB) | **kusii** | | (cf. J. 1988:67) |
| Tr.(CCA) | **'gEhl** | | (cf. J. 1988:67) |
| By.(ECB) | **kasko** | | (cf. J. 1988:67) |
| Kr.(WCB) | **kwEsu** | | (cf. L. 1986:109, No. 20) |
| Dr.(WCA) | **ween** | | (cf. L. 1986:109, No. 20) |
| Mm.(ECB) | **?assu** | | (cf. J. 1988:67) |

| | | | |
|---|---|---|---|
| 5 | 'thirst' | *kEzEm | (cf. NM. 1977b:32, No. 130) |
| | Hs.(WCA) | k'iishìi | (AH) |
| | Tr.(CCA) | xujùm | (cf. also N/M. 1966:44, No. 331) |
| | Bl.(WCA) | kEzEm | |
| | Ng.(WCB) | gEji | |

| | | | |
|---|---|---|---|
| 6 | 'stir up' | ? | |
| | Sr.(WCA) | nak'u | |
| | Pa.(WCB) | nak'u | |
| | My.(WCB) | nEk' | |
| | Hs.(WCA) | n[illegible]k'èa 'grind [illegible]' | (AH) |

| | | | |
|---|---|---|---|
| 7 | 'leg, foot' | *asE | (cf. NM. 1977b:29, No. 81) |
| | | **sio | (cf. L. 1986:117, No. 101) |
| | | *skr | (cf. JS. 1981:162) |
| | Hs.(WCA) | k'afàa | (AH) |
| | Rn.(WCA) | say | |
| | Gr.(WCB) | asàn | (cf. Jg. 1988:186) |
| | Msg.(CCB) | azi | |
| | Lg.(CCB) | asE | |
| | Ms.(MS) | ase-nu | |
| | Sh.(WCA) | sEka?ù | (cf. L. 1986:117, No. 101) |
| | Kr.(WCA) | sìyo | (cf. L. 1986:117, No. 101) |
| | Dr.(WCA) | yoo | (cf. L. 1986:117, No. 101) |
| | Ang.(WCA) | shii | (cf. L. 1986:117, No. 101) |

| | | | |
|---|---|---|---|
| 8 | 'refuse' | *kurE | (cf. NM. 1977b:30, No. 103) |
| | | **kud'(-V) | (cf. L. 1986:102, No. 142) |
| | Hs.(WCA) | k'i | (AH) |
| | Dr.(WCA) | kur-i | (cf. L. 1986:102, No. 142) |
| | Ng.(WCB) | kurE | |
| | Msg.(CCB) | NgEl | |
| | Kk.(WCA) | kuri | |
| | Gs.(CCA) | kar | |
| | Gr.(WCB) | ngai | (cf. Jg. 1988:187) |
| | Kr.(WCA) | kud'-u | (cf. L. 1986:102, No. 142) |

| | | | |
|---|---|---|---|
| 9 | 'dig' | *'waf- | (cf. S. 1982:16) |
| | Hs.(WCA) | k'waafii | 'fill in where crops fail to germinate' |
| | Bl.(WCA) | ?oppuu- | (cf. S. 1982:16) |
| | Gr.(WCB) | a-wi | 'dig up, take out' (cf. Jg. 1988:184) |

| | | | | |
|---|---|---|---|---|
| 10 | 'be dry' | | ***f-'y-** | (cf. S. 1982:14) |
| | Hs.(WCA) | **fak'oo** | 'hard ground' | |
| | Bd.(WCB) | **po'y'yuu-** | | (cf. S. 1982:14) |
| | Gr.(WCB) | **ga?àr** | 'dry season' | (cf. Jg. 1988:184) |
| 11 | 'calabash' | | ***kul-** | (cf. S. 1982:16) |
| | | | ***kwd(d') (-m)** | (cf. JS. 1981:58) |
| | Hs.(WCA) | **k'waryaa** | | (cf. S. 1982:16) |
| | Bd.(WCB) | **kula** | | (cf. S. 1982:16) |
| 12 | 'knife' | | ***s-G-** | (cf. N/M. 1966:236, No. 56) |
| | | | ***ṣuk-** | (cf.NM 1977b:28 No. 77) |
| | | | ****čuk** | (cf L 1986:117 No. 98) |
| | | | ***sk or syk (?) (-l,-t,-n)** | (cf. JS 1981:157) |
| | Hs.(WCA) | **wuk'aa** | | (AH) |
| | Tr.(CCA) | **hlugu** | | |
| | Gdr.(CCB) | **hloho** | | |
| | Sh.(WCA) | **shuk** | | (cf. L. 1986:117, No. 98) |
| | Ang.(WCA) | **cùk** | | (cf. L. 1986:117, No. 98) |
| | Ngm.(WCB) | **soki** | | (cf. N/M. 1966:236, No. 56) |
| | Ank.(WCA) | **shik** | | (cf. N/M. 1966:236, No. 56) |
| 13 | 'black, darkness' | | ***lm (d-, b-, k-) (?)** | (cf. JS. 1981:44) |
| | Hs.(WCA) | **bak'ii** | | (cf. Sk. 1971:308, No. 32) |
| | Bd.(WCB) | **pElka** | | (cf. Sk. 1971:308, No. 32) |
| | Bm.(CCB) | **tsilim** | | (cf. Sk. 1971:306, No. 20) |
| | Hs.(WCA) | **k'irin/tilim/culum** | | (cf. Sk. 1971:306, No. 20) |
| | Kt.(CCB) | **cilim** | | (cf. Gr. 1970:53) |
| | So.(ECB) | **silim** | | (cf. Gr. 1970:53) |
| 14 | 'throat' | | ? | (cf. Sk. 1971:308) |
| | Hs.(WCA) | **mak'oogwaroo** | | (cf. Sk. 1971:308, No. 36) |
| | Lg.(CCB) | **ŋkuruXi** | | (cf. Sk. 1971:308, No. 36) |
| | Bm.(CCB) | **ŋgorokullo** | /nk > k'/ | (cf. Sk. 1971:308, No. 36) |
| | Tr.(CCA) | **XùXwàr** | | (cf. NM. 1964:38, No. 66) |
| 15 | 'horn' | | ****b'YiVm** | (cf.L. 1986:115, No. 87) |
| | | | ***mk (a) (t-; -m)** | (cf. JS 1981:142) |
| | Hs.(WCA) | **k'ahoo** | | (cf. Sk. 1971:305 No. 1) |
| | Lg.(CCB) | **kaätlu** | | (cf. Sk. 1971:305 No. 1) |
| | Sh.(WCA) | **gyilu** | | (cf. L. 1986:115, No. 87) |
| | Dr.(WCA) | **b'ili** | | (cf. L. 1986:115, No. 87) |
| | Kr.(WCA) | **b'èelEm** | | (cf. L. 1986:115, No. 87) |

| | | | |
|---|---|---|---|
| 16 'add' | | ? | |
| Hs.(WCA) | **k'aar-** | | (cf. Sk. 1971:305, No. 4) |
| Bm.(CCB) | **kalgu** | | (cf. Sk. 1971:305, No. 4) |

| | | | |
|---|---|---|---|
| 17 'brain' | | ? | |
| Hs.(WCA) | **k'wak'walwaa** | | (cf. Sk. 1971:306, No.17) |
| Tr.(CCA) | **xuxuyni** | | (cf. NM. 1964:37, No. 50) |
| Kr.(WCA) | **ndulaka** | | (cf. L. 1986:109, No. 22) |

| | | | |
|---|---|---|---|
| 18 'smoke' | | ***'Jan** | (cf. NM. 1977b:32, No. 118) |
| Hs.(WCA) | **hayaak'ii** | | (cf. Sk. 1971:308, No. 34) |
| Wr.(WCB) | **k'yanu-na** | | |
| Tr.(CCA) | **'gEn** | | (cf. NM. 1964:40, No.137) |
| Msg.(CCB) | **'yar** | | |
| Bl.(WCA) | **oloki** | /nk/ > / k'/ | (cf. Sk. 1971:308, No.34) |

| | | | |
|---|---|---|---|
| 19 'forge' | | ****kVl (-V)** | (cf. L. 1986:104, No. 67) |
| Ang.(WCA) | **kolom** | | (cf. L. 1986:104, No. 67) |
| Hs.(WCA) | **k'er-a** | | (cf. L. 1986:104, No. 67) |

In the West, Central and East branches, Hausa /k'/ corresponds variously to /d', k, 'g, ?, hl, or 'y/. The proposed laws that might account for these correspondences are beyond the scope of this work.

### 2.13.1 Dialect Variation

Dialect variation between the present day dialects of Hausa provides several variants of /k'/.

| | Kano | Katsina/ Sokoto | Bauchi/ Zaria | Dogon-Doutchi/ Zamfara | Ghana | Guddiri |
|---|---|---|---|---|---|---|
| 'handle of hoe' | k'ootàa | b'ootàa | k'ootàa/ kootàa | | | |
| 'ideophone' | suk'ùt | sub'ùt | suk'ùt/ sukùt | suk'ùt/ su'ùt | sukùt | su'ùt |
| 'calabash' | k'òok'oo | k'òok'oo | k'òok'oo/ kòokoo | k'òok'oo/ ?òo'oo | kòokoo | ?òo'oo |
| 'earth' | k'asaa | k'asaa | k'asaa/ kasaa | k'asaa/ ?asaa | kasaa | ?asaa |
| 'bone' | k'àshii | k'àshii | k'àshii/ kàshii | k'àshii/ ?àshii | kàshii | ?àshii |
| 'to be full with food' | k'òoshi | b'òoshi | k'òoshi/ kòoshi | k'òoshi/ ?òoshi | kòoshi | ?òoshi |
| 'feeding or pecking eg.chicken' | k'òotoo | b'òotoo | k'òotoo/ kòotoo | k'òotoo/ ?òotoo | kòotoo | ?òotoo |
| 'wooden spoon' | k'òoshiyàa | b'òoshiyàa | k'òoshiyàa kòoshiyàa | k'òoshiyàa ?òoshiyàa | kòoshiyàa | ?òoshiyàa |

cf. Ahmed and Daura (1970:83), also personal correspondence with Sulaiman Ibrahim, a Katsina Hausa speaker and Idris Mohammed, a Hausa speaker from Ghana. /k'/ in Kano alternates with /b':k'/ in Katsina/Sokoto, /k':k/ in Bauchi/Zaria, /k':?/ in Dogon Doutchi, /k/ in Ghana and /?/ in Guddiri.

### 2.13.2 Borrowing. Arabic /q/ > Hausa /k':k/.

According to tradition, Islamic and Arabic influence started to be felt in Hausa society at around the 13th-14th century AD, (cf. Greenberg (1947)) and Gregersen (1967 for a discussion on Arabic loans into Hausa). Arabic words that are borrowed into Hausa form a group that are not part of the day-to-day vocabulary of Hausa speakers and often have learned connotations. The words that are borrowed include the category associated with law and theology, in short "Koran words" (to borrow the term used by Hiskett (1965). Hausa /k'/ should correspond to Arabic /q/ (as it would be expected that /ts/ should represent Arabic /ṣ/) but on the contrary /k'/ does not always do so (cf. below). Instead /k'/ variously alternates with /k/ in words containing /q/ in Arabic. For example:

| A | Arabic | Hausa |
|---|---|---|
| 'quick perception' | **Xaaziq** | **haazìk'ii/ haazìkii** |
| 'koran' | **al-qur?an** | **?àlk'ùr̃?aanìi/ ?àlkùr̃?aanìi** |
| 'principle' | **qa.?ida** | **k'aa?idàa/ kaa?idàa** |
| 'judge' | **qa.ḍi** | **?àlk'aalii/ ?àlkaalii** |
| 'division into shares' | **qisma** | **k'isiimaa/ kisiimaa** |

Rule: Ar. /q/ > Hs. /k'/ : /k/.

| B | | |
|---|---|---|
| 'unbeliever' | **kaafir** | **kaafìr̃ii** |
| 'lead sulphide' | **kuhl** | **kwâllii** |
| 'penis' | **Dak̇ar** | **?àzzakàr̃ii** |
| 'district head' | **ḥa.kim** | **haakìmii** |
| 'deputy' | **ẇaki.l** | **wàkiilìi** |

Rule: Ar. /k/ > Hs. /k/.

Cf. Greenberg (1947), with corrections to final vowel-length.

The situation in group A is that the Arabic /q/ is realized as either /k'/ or /k/ in free variation. In group B, the situation is quite straightforward: Hausa /k/ represents Arabic /k/.

## 2.14 Comparative Wordlist for /ts/

| | | | | |
|---|---|---|---|---|
| 1 | 'stay, stop' | *d'arE | | (cf. NM. 1977b:32, No. 123) |
| | | *d'yar- | | (cf. S. 1982:9) |
| | | **yVl(-V) | | (cf. L. 1986:124, No. 170) |
| | Hs.(WCA) | ts'ayàa | | (AH) |
| | Kr.(WCA) | 'yaaru | | |
| | Bl.(WCA) | 'yoruu- | | (cf. S. 1982:9) |
| | Af.(CCB) | ts'arga | | |
| | Mub.(ECB) | d'ar | | |
| | Gr.(WCB) | tabi | | (cf. Jg. 1988:188) |
| | Dr.(WCA) | yìri | | (cf. L. 1986:124, No. 170) |
| | Ang.(WCA) | yàl | | (cf. L. 1986:124, No. 170) |

| | | | | |
|---|---|---|---|---|
| 2 | 'suck' | *sEb'E | | (cf. NM. 1977b:32, No. 125) |
| | | *smb (-d') | | (cf. JS. 1981:255) |
| | Hs.(WCA) | tsootsèe | | (AH) |
| | Gr.(WCB) | b'ub'i | | (cf. Jg. 1988:88) |
| | Kt.(CCB) | s'afE | | |
| | Ke.(ECA) | sob'e | | |
| | Zm.(MS) | sob'o | | |
| | Mk.(ECB) | sib'- | 'drink' | |
| | Bc.(CCA) | sEb'E | 'drink' | |
| | Mf.(CCA) | asEb'- | | |

| | | | | |
|---|---|---|---|---|
| 3 | 'kill' | *d- | | (cf. NM. 1977b:28, No. 75) |
| | | **duk (-V) | | (cf. L. 1986:116, No. 95) |
| | | *dk or *d-k | | (cf. JS. 1981:154) |
| | Zr.(WCB) | tsi(?) | | |
| | Mg.(CCA) | tsa | 'beat' | (cf. LD. 1968:65) |
| | Br.(CCA) | lzabwa | 'beat' | (cf. LD. 1968:64) |
| | Ms.(MS) | ci | | |
| | So.(ECB) | da | | |
| | Jg.(ECB) | d- | | |
| | Mg.(CCA) | tsia | | (cf. HF. 1963:25) |

4 'thunderclap, shouting in a loud voice' * ?

| | | | |
|---|---|---|---|
| Hs.(WCA) | tsaawaa | | (AH) |
| Mg.(CCA) | ntsàntsà | 'shouted' | (cf. LD. 1968:65) |
| Mg.(CCA) | ntsàntsà | 'shouted' | (cf. HF. 1963:31) |

5 'pick up' * ?

| | | |
|---|---|---|
| Hs.(WCA) | tsìinee, tsìntaa | (AH) |
| Mg.(CCA) | mnptsàkù | (cf. LD. 1968:65) |
| Mg.(CCA) | mtsàkù | (cf. HF. 1963:30) |

| | | | | |
|---|---|---|---|---|
| 6 | 'bird' | | *yd' (-t, -k) | (cf. JS. 1981:41) |
| | | | *d'Ey- | (cf. NM. 1977b:22, No. 6) |
| | | | *k-d'-(n) | (cf. N/M. 1966:241, No. 124) |
| | Hs.(WCA) | tsuntsuu | | (cf. Sk. 1971:307, No. 27) |
| | Br.(CCA) | tsuvoy | | (AH) |
| | Mg.(CCA) | tsuvuy | | (AH) |
| | Lg.(CCB) | sisia | | (cf. Sk. 1971:307, No. 27) |
| | Mg.(CCA) | tsEvEr | | (AH) |
| 7 | 'squeeze' | | * ? | |
| | Hs.(WCA) | maatsèe/tsaamèe | | (AH) |
| | Br.(CCA) | tsarà | | (cf. Kr. 1981:56, No. 396) |
| | Mg.(CCA) | nsitE | | (cf. Kr. 1981:86, No. 396) |
| 8 | 'tamarind' | | * ? | (cf. Sk. 1971:306, No. 25) |
| | Hs.(WCA) | tsaamiyaa | | (cf. Sk. 1971:306, No. 25) |
| | Bm.(CCB) | tamugu | | (cf. Sk. 1971:306, No. 25) |
| 9 | 'urine' | | *ps?r | (cf. JS. 1981:279) |
| | | | **yVndVn | (cf. L. 1986:127, No. 197) |
| | | | *f-'y-r | (cf. S. 1982:13) |
| | Hs.(WCA) | fitsaarii | | (cf. S. 1982:13) |
| | So.(ECB) | sori | | (cf. Sk. 1971:309, No. 41) |
| | Df.(WCA) | sar | | (cf. Sk. 1971:309, No. 41) |
| | Bl.(WCA) | 'yofaa-bu?um | | (cf. S. 1982:13) |
| | My.(WCB) | ts@p@r | | (cf. S. 1982:13) |
| | Gr.(WCB) | b'aashi | | (cf. Jg. 1988:188) |
| | Ng.(WCB) | v@d'au | | (cf. S. 1982:13) |
| | Kr.(WCA) | 'yandEy | | (cf. L. 1986:127, No. 197) |
| | Dr.(WCA) | yendin | | (cf. L. 1986:127, No. 197) |
| 10 | 'rock, stone' | | * ? | (cf. Sk. 1971:309, No. 40) |
| | Hs.(WCA) | duutsee | | (cf. Sk. 1971:309, No. 40) |
| | Sr.(WCA) | d'ušuu | | (cf. Sk. 1971:309, No. 40) |
| | Kr.(WCA) | goco | | (cf. Sk. 1971:309, No. 40) |
| 11 | 'fat' | | *k-'y-r | (cf. S. 1982:13) |
| | | | *kd'yr | (cf. JS. 1981:99) |
| | Hs.(WCA) | kitsee | | (cf. S. 1982:13) |
| | Tr.(CCA) | XÈ'Jir | | (cf. NM. 1964:43, No. 289) |
| | My.(WCB) | ha?ar | | (cf. S. 1982:13) |
| | Bl.(WCA) | shid'or | | (cf. S. 1982:13) |
| 12 | 'fear' | | ? | |
| | Hs.(WCA) | tsòoroo | | (AH) |
| | Mg.(CCA) | ntswa | | (AH) |
| | Gr.(WCB) | b'òolo | | (cf. Jg. 1988:184) |

13 'guinea corn' ***'y-l-** (cf. S. 1982:16)

| | | | |
|---|---|---|---|
| Hs.(WCA) | **hatsii** | | (cf. S. 1982:16) |
| Bl.(WCA) | **'yala** | | (cf. S. 1982:16) |
| Gr.(WCB) | **àu** | | (cf. Jg. 1988:185) |

14 'jump up' ***pr(i,a)** (cf. JS. 1981:153)

| | | | |
|---|---|---|---|
| Hs.(WCA) | **tsallee** | | (AH) |
| Gr.(WCB) | **d'ooli** | 'jump over' | (cf. Jg. 1988:185) |

15 'chop' ***lzwr** (cf. JS. 1981:81)

| | | | |
|---|---|---|---|
| Hs.(WCA) | **daatsèe** | | (AH) |
| Ngm.(WCB) | **da?a kit** | | (cf. Kr. 1981:91) |
| Kr.(WCA) | **d'Èd'u** | | (cf. Kr. 1981:91) |

16 'guinea fowl' ***z-b-(n)** (cf. N/M 1966:241, No. 132)
***zaban** (cf. NM 1977b:27, No. 65)

| | | | |
|---|---|---|---|
| Br.(CCA) | **tsIvur** | | (cf. Kr. 1981:54, No. 168) |
| Mg.(CCA) | **tsivur** | | (cf. Kr. 1981:54, No. 168) |
| Mg.(CCA) | **tsEvEr** | | (cf. HF. 1963:25) |
| Br.(CCA) | **tsivira** | | (cf. N/M. 1966:241, No. 132) |
| Gs.(CCA) | **tsuvoy** | | (cf. NM. 1977b:27, No.65) |
| Hs.(WCA) | **zàaboo** | | (AH) |

Note that Hausa /ts/ corresponds variously to /ts: :b':d':t:gh:'J:xh:s/ in the three branches (West, Central and East) Chadic.

Some of the proposed sound laws that might account for these correspondences are given in Klengenheben (1928), NM (1977a) and Schuh (1972).

2.14.1 Dialect Variation

Dialect variants are illustrated in the following examples:

| | Kano | Bauchi/ Zaria | Ghana | Katsina/ Sokoto | Dogon Doutchi |
|---|---|---|---|---|---|
| 'comb out hair' | **tseefèe** | **tseefèe/ seefèe** | **seefèe** | **t'eefèe/ c'eefèe** | **tseefèe/ c'eefèe** |
| 'suck' | **tsootsèe** | **tsootsèe/ soosèe** | **soosèe** | **t'oot'èe/ c'ooc'èe** | **tsootsèe/ c'ooc'èe** |
| 'pointed edge' | **tsìinii** | **tsìinii/ sìinii** | **sìinii** | **t'ìinii/ c'ìinii** | **tsìinii/ c'ìinii** |
| 'Katsina town' | **katsina** | **katsina/ kasina** | **kasina** | **kat'ina/ kac'ina** | **katsina/ kac'ina** |
| 'stone' | **duutsèe** | **duutsèe/ duusèe** | **duusèe** | **duut'èe/ duuc'èe** | **duutsèe/ duuc'èe** |
| 'movement' | **mootsìi** | **mootsìi/ moosìi** | **moosìi** | **moot'ìi/ mooc'ìi** | **mootsìi/ mooc'ìi** |
| 'poverty' | **tsìyaa** | **tsìyaa/ sìyaa** | **sìyaa** | **t'ìyaa/ c'ìyaa** | **tsìyaa/ c'ìyaa** |
| 'escape, run away' | **tseerèe** | **tseerèe/ seerèe** | **seerèe** | **t'eerèe/ c'eerèe** | **tseerèe/ c'eerèe** |

/ts/ in Kano (East Hausa) alternates with /t':c'/ in Katsina and in Dogon Doutchi (West Hausa). Similarly /ts/ and /s/ are also in free variation in Zaria and Bauchi dialects. Geographically, the two dialects are closer to Kano dialect (East Hausa). Ghana Hausa consistently has the plain counterpart /s/.

### 2.14.2 Borrowing from Arabic to Hausa

Borrowed words from Arabic into Hausa are characterized by variation in the phonetic treatment of the Arabic original. The distinction between plain and emphatic consonants is preserved, with reinterpretation of the emphatics. Such a process is found in Sindhi (cf. Blust (1980)).

Hausa /ts/ variously alternates with /d':ts:c':t'/ in words containing /ṭ/ in Arabic. The commonest examples are words that represent personal names. See examples below.

| | Arabic | East Hausa | West Hausa |
|---|---|---|---|
| 'personal name' | **taahir**<br>**ṭayyabaa**<br>**ṭayyabuu** | **d'aahir̃u**<br>**d'ayyabaa**<br>**d'ayyabuu**<br>**faad'imatu** | **tsaahir̃u**<br>**tsayyabaa**<br>**tsayyabuu**<br>**hwaatsimatu** |
| 'accident' | **xaṭar** | **had'àr̃ii/**<br>**hatsàr̃ii** | **hatsàr̃ii** |
| 'good behaviour' | **ṭabi?̲a** | **d'àbi?̲àa** | **tsàbi?̲àa** |
| 'sexual intercourse' | **waṭ?̲** | **wàad'a?̲ii** | **wàat'a?̲ii/**<br>**wàac'a?̲ii** |
| 'to sin' | **xaṭa?̲** | **hàd'a?̲u** | **hàt'a?̲u/**<br>**hàc'a?̲u/hàtsa?̲u** |

Sources: Greenberg (1947), Ahmed and Daura (1970), Zaria (1982).

Arabic /ṭ/ corresponds to Hausa /d':ts:c':t'/ according to the dialect area, (cf. Bargery (1934:xxiii) and James and Bargery (1925)).

### 2.14.3 Correspondences Between Hausa /ts/ and Guruntum /b'/, /d'/.

| | | Hausa | Guruntum | |
|---|---|---|---|---|
| 1 | 'fear' | **tsòoroo** | **b'òolo** | (cf. Jg. 1988:184) |
| 2 | 'cleanliness' | **tsabtàa** | **b'iisi** | 'white' (cf. Jg. 1988:189) |
| 3 | 'suck' | **tsòotsaa** | **b'ub'i** | (cf. Jg. 1988:188) |
| 4 | 'jumping' | **tsallee** | **d'ooli** | (cf. Jg. 1988:185) |
| 5 | 'sour' | **tsaamii** | **saab'id'i** | (AH) |

The last example could be explained by assuming that the Guruntum word has a prefix saa-. This is the only example found.

## 2.15 Summary

This chapter provides a general overview of the different comparative studies on the Chadic glottalic consonants. Claims were presented and criticised. The languages cited were taken to be representative of the respective branches of the Chadic family.

Of special interest are the various reconstructions of the ejectives among the established Chadic glottalic consonants. The results represented a scarcity or lack of cognates across the four branches for /ts/, /k'/ and /'y/. The question remains: why were there not enough cognates found across the branches, which according to the classifications are very closely related? There seem to be three possible answers to this question:

1. the vocabularies included in the wordlist are not the appropriate ones upon which to base a Chadic comparative study;
2. the time separation among the groups obscures the reconstruction of these cognates, for example through semantic shift; or
3. there is insufficient cross-language data.

Since all the vocabulary items included in the comparative list are items which are considered to be Chadic items for comparative purposes, one can therefore say that the vocabulary items used in this study are most appropriate. It may be possible that the problem of semantic shift has contributed to the scarcity or lack of cognates found across the languages. However, the ultimate problem with this comparative exercise on the four branches of Chadic lies with the unavailability of data. The best way to remedy this is for more data to be made available, by reseachers and linguists analysing Chadic languages in great detail over an adequate length of time. One way to ease the burden on the few linguists interested in the study of the Chadic languages would be to encourage speakers of these languages to become linguistically critical of, and interested in, the study of their languages.

Finally, the reconstructions seem very interesting and need further investigation because:

1 we found a language (Hausa) which, in general, seems to be very consistent with regard to its phonological development but has developed unusual (for Chadic) phonemes;
2 from a general phonetic point of view, one finds that some of the reconstructions are odd, for example, one does not expect a sonorant to change into an ejective; see Section 2.13.
3 there is very little study done on the origin of /'y/.

## 2.16 NOTES

1 In these studies, however, several of the Chadic languages cited are only represented by entries or samples taken down in the field. Individual comparativists make possible assumptions from the scanty data available to them. The phonological changes between the branches have not been sufficiently demonstrated. How difficult and unclear such attempts are is evident in the degree of dissimilarities between proposed protoforms by different comparativists. For example:

| | Newman (1977b:26) | Jungraithmayr and Shimizu (1981:111) |
| --- | --- | --- |
| 'fly' (n) | ***diwa** | ***k'db** |

Within the Chadic family, there also exist some practical dictionaries of individual languages, for example Bargery's (1934) and Abraham's (1962) dictionaries of Hausa, and Schuh's (1981) dictionary of Ngizim, but we lack etymological dictionaries that are complete and dependable. However, while these dictionaries are not etymological, they serve as good sources for comparative purposes.

2 More recent Chadic estimates suggests that the Chadic language family is comprised of some one hundred and forty languages (cf. Fleming 1983:19).

3 What they consider as "counterexamples" are forms which have been recorded by earlier linguists with inadequate training who have failed to distinguish consistently between voiced and glottalized consonants. For example, Schön (1876) noted the peculiarity of /b'/ and sometimes writes it as /gb/.

4 It makes a big difference to the reconstruction of the glottalized sounds in PC, whether one assumes with N/M (1966) and JS (1981) that they existed as single sounds at the very begining of Chadic or accepts the alternative assumption that they are sounds which are the product of a language process of merging and systematizing (cf. Skinner (1971). The latter is possible but it poses serious problems for /ts/, /k'/ and /'y/. The problems will not be discussed here.

5 Hausa **m ad'ìi** 'sweet drink' may be cognate with Guruntum:**mwad'ami** 'sweetness' (Jaggar

(1988:188)). If so, then the idea of borrowing raised by Skinner may not necessarily be the case.

6 Schuh has argued that only when sound correspondences have been established for the internal relationships of the branches of Chadic can a firmer basis be set for establishing sound correspondences for the entire Chadic family. He therefore limited himself to the study of the West Chadic branch only.

7 Dogon Doutchi is one of the major dialect areas in the Niger republic. cf. Zaria (1982).

# Chapter Three

Hausa (Chadic) Glottalic Correspondences in Afroasiatic.

## 3.1 Introduction.

The aim of this chapter is to present data and claims regarding Hausa/Chadic and Afroasiatic (hereafter AA) glottalic correspondences. Effort has therefore been made to relate the Hausa glottalized phonemes, /b'/, /d'/, /ts/, and /k'/ to corresponding phonemes in other AA languages. The glottalized phoneme /'y/ is not to be discussed here because it is lexically rare and also lacks systematic correspondences within the other families. Another aim of the chapter is to serve as a reference for comparative work between Chadic languages and other AA languages - the list of items cited is accompanied by their sources. This allows easy cross reference with major works in the field.

Since Chadic belongs to AA, it is therefore obvious that a deeper insight into the nature of the Chadic family is impossible unless material from the other AA branches - Berber, Cushitic, Omotic, Egyptian and Semitic - is taken into consideration. Unlike the earlier works where comparisons were mainly within the other branches of the AA phylum (except Greenberg 1950, 1955, 1970, and Diakonoff (1965), an effort has been made to relate the Chadic lexical items with identifiable cognates in other AA languages. No attempt has been made to set up a new theory regarding the origin of the glottalic consonants.

## 3.2. Notes on the Data and Abbreviations.

This chapter does not attempt to give the complete listing of PAA phonemes, rather what it aims at is to try to present data which shows correspondences between Chadic glottalics and phonemes in other AA languages. Only a selection of etymologies are used here. There are many more to be found which are not apparent in this list.

Language Abbreviations:

Semitic (Sem):

| | |
|---|---|
| Ar | Arabic |
| Akk | Akkadian |
| Heb | Hebrew |
| Aram | Aramaic |
| Amh | Amharic |

Ancient Egyptian (An Eg):

| | |
|---|---|
| Eg | Egyptian |
| Cop | Coptic |

Cushitic (Cush)[1]:

| | |
|---|---|
| Ag | Agau |
| Bed | Bedawye (= Beja) |
| Bog | Bogo (=Bilin) |
| Km | Kamir |
| Au | Auara (Quara) |
| Som | Somali |
| *Or | Oromo |
| Af | Afar |
| Irq | Iraqw |
| Sa | Saho |

*Formerly Galla.

Chadic (Ch):

| | |
|---|---|
| Hs | Hausa |
| Kur | Kuri (= Dialect of Buduma) |
| Mub | Mubi |
| Msg | Musgu |
| Ng | Ngizim |
| So | Sokoro |
| Kb | Karbo |
| Wr | Warji |
| Lg | Logone |
| Bl | Bole |
| Mg | Margi |
| Ang | Angas |
| Bc | Bachama |
| Mand | Mandara |
| Bud | Buduma |

Berber (Ber):

| | |
|---|---|
| Shl | Shilha |
| Sou | Sous |
| To | Touareg |
| Kab | Kabyle |

Indo European (Id):

| | |
|---|---|
| Eng | English |

Author Abbreviations and Sources of Comparative Wordlists.

| | |
|---|---|
| C: | Cohen (1947) |
| DK: | Diakonoff (1965, 1974) |
| G: | Gouffé (1969/70) |
| GR: | Greenberg (1950) (3rd ed 1970) |
| H: | Hodge (1966, 1968, 1969) |
| NP: | Pilszczikowa (1960) |
| V: | Vycichl (1968) |
| P: | Parsons (1955) |
| AH: | Haruna |

Apart from Hausa I have not given many examples from other Chadic languages here so as to avoid repetition. Sometimes, even though an author did not cite Hausa cognates, I have cited the modern Hausa forms. For examples from other Chadic languages the reader should refer to Chapter two and, for other correspondences, see other sources in the wordlist.

## 3.3 Approaches to the Classification of AA: Membership and Criteria for Membership.

The term "Afroasiatic" - a family of genetically related languages represented both in Africa and Asia and developed from a common parent language - was introduced by Greenberg (1950:57) to replace "Hamito-Semitic" (Lepsius 1863) which consisted of Semitic, Egyptian, Berber, and Cushitic (cf. below for reasons for the change of name).[2]

Cohen (1924, 1947 and 1952) and Mukarovsky (1966) used the term "Chamito-Semitic". Lepsius (1863) had earlier used the term "Hamitic" which included Egyptian, Cushitic, Berber and Hausa plus Hottentot which he grouped into one family (Hamitic) distinct from Semitic. Meinhof (1912 and 1915) following Lepsius not only retained Hausa among the Hamitic languages but also added Fula (Niger-Congo) and Masai (Nilo-Saharan) into the family, and endowed the family with racial characteristics, both physical and psychological (see Newman (NM) 1980:8). AA is also called "Semito-Hamitic" by Benfey (1869), Rössler (1982), and Rabin (1977); "Afrasian" ("half African and half Asiatic") by Diakonoff (1965 and 1974), Dolgopolsky (1973); "Erythraic" by Reinisch (1873) and Tucker (1967b); and "Lisramic" by Hodge (1975, 1976 and 1987). A general review and useful summary of earlier works on AA can be found in Cohen (1947), Hodge's survey (1971 and 1983) and Diakonoff (1965, 1974 and 1975).

Since Greenberg's (1950, 1952 and 1955) major revision and expansion of the AA family, there have not been many changes other than a few revisions such as Fleming's suggestion (1969, 1974, 1976 & 1983) that Omotic should be recognised as a distinct family rather than considered a branch of Cushitic. Fleming suggests that "the co-equal or coordinate branches of Greenberg's AA are no longer co-equal" (Fleming 1983:23). He therefore splits Cushitic into Cushitic and Omotic and considers Omotic as a sixth branch of the AA family (cf. Fleming and Bender (1976:39) and Hudson (1976:98). Similarly Hodge (1976) like Fleming (1974) has classified his Lisramic (AA) family into six branches. He declared: "Lisramic is here understood to refer to six presumably related groups of languages: Semitic, Egyptian, (including Coptic), Cushitic, Omotic, Berber and Chadic" Hodge (1976:43). The hypothesis (of increasing the number of sub-families) was, however, not accepted by all. Even recently Newman (1980) rejected this proposal. Nevertheless, Hetzron (1980:101) (as quoted by Newman 1980) went further and suggested that Cushitic should be divided again, separating off Beja and treating it as a separate branch of AA. The reclassifications being proposed by Hetzron are yet to receive wider acceptability. And the studies are mentioned here only to put into perspective those studies which deal with the larger question of relationships within AA.

The most generally accepted view today is that the AA phylum contains six parallel branches (see Fleming (1974, 1976 and 1983)): Ancient Egyptian, Semitic, Cushitic, Omotic, Berber, and Chadic (see Fig. 3.1.). Each of these six branches of AA is also considered as a language family (cf. Greenberg 1970). The notion of the character and the degree of the relationship between the AA languages based on their phonological inventory is vague. Many works in the field of historical comparison that treat the phonological systems of the AA languages as a whole have failed to impress many scholars. Some linguists have denied the genetic affinity of the Chadic languages with the other branches of the AA, while others like Greenberg accept it. Some scholars have expressed doubt concerning the AA character of some languages but not of others.

As part of his classification of the African languages, Greenberg (1950) proposed that Chadic be incorporated as an integral part of the AA family. He remarked:

> "For no other proposed Hamito-Semitic African languages can anything be presented remotely approaching the morphological and lexical resemblances adduced here for the Chad languages. We arrive therefore at the definite conclusion that the language family traditionally named Hamito-Semitic has five coordinate branches: (1) Semitic, (2) Berber, (3) Ancient Egyptian, (4) Cushitic, and (5) Chad" Greenberg (1950:55).

Greenberg arrived at this conclusion based on the recognition of lexical items and grammatical morphemes sounding alike. His method of classification has been described by Fodor who says:

> "Greenberg is rightly aware of the shortcomings of the earlier attempts at classification, and creates therefore his own method solely on the basis of linguistic evidence, to the exclusion of ethnological and other external criteria. The basic principle of his method is that comparisons must be made on the strength of resemblances of both phonetic form and meaning, i.e the method is not based on the agreement of phonetic form only, or of meaning only; further on, it takes into consideration not only the roots, but also the relational morphemes, thus the evidence of grammar as well. And what is the main thing, Greenberg draws his inferences not from one or two cases taken at random, but he makes a "mass comparison" (Greenberg 1963:1) drawing on as many data as possible" Fodor (1982:22).

Greenberg's works have made several major contributions to the study of Afroasiatic linguistics:

1 They allowed more precise knowledge of the internal structure of AA than had been provided by earlier classifications.

2 He set up a new methodological system "mass comparison" (based on lexico-statistics), for establishing relationships using a number of languages

from all branches of AA.

3 Greenberg's analysis provided an impetus to the study of individual Chadic languages (cf. Newman and Ma (N/M) (1966), NM (1971, 1977), Skinner (1971, 1977), Jungraithmayr and Shimizu (1981) and Schuh (1982)).

In considering the inclusion of Chadic within AA, three claims were made by Greenberg, none of which were original to him (Newman 1980:4-5). The three points are:

1 That Hausa, in spite of its numerical significance, was phylogenetically just one of a number of related languages in the area. This means that, in considering the possible relationship of Hausa to Egyptian or Berber or Semitic, one had to consider the whole Chadic group of which Hausa is a member and not just Hausa in isolation.

2 The second is Greenberg's rejection of Lepsius' "Hamitic" family and the traditional "Hamito-Semitic" dichotomy. Greenberg argued for its replacement by an overall AA phylum with five parallel families with equal status.

3 Greenberg showed that Chadic was indeed Afroasiatic. For the first time Chadic was clearly defined and assigned as a parallel branch equal in status with the other member branches.

The major evidences used by Greenberg for establishing the five coordinate branches within AA were:

1 basic vocabulary comparisons and
2 sound correspondences.

Other criteria have also been used for determining linguistic relationships, for example, comparative morphology (e.g verb forms) by Polotsky (1964), Rundgren (1955 and 1961), and Hodge (1968:23-24). Cohen, (1947:43-45) for example, gives verb forms, both prefixal and suffixal, along with pronouns suffixed to nouns and verbs, as being proof of relationship. Lukas (1936) classified some of the languages of the Chadic family into two separate groups, "Chado-Hamitic" and "Mandara", based mainly on the spurious criterion of grammatical gender. Greenberg (1955:53-55) lists morphologic features which the Chadic languages share with other languages in the AA family. Similarly semantics and syntax have been used as a criterion (cf. Ullendorff (1958) and Tucker (1967a)).

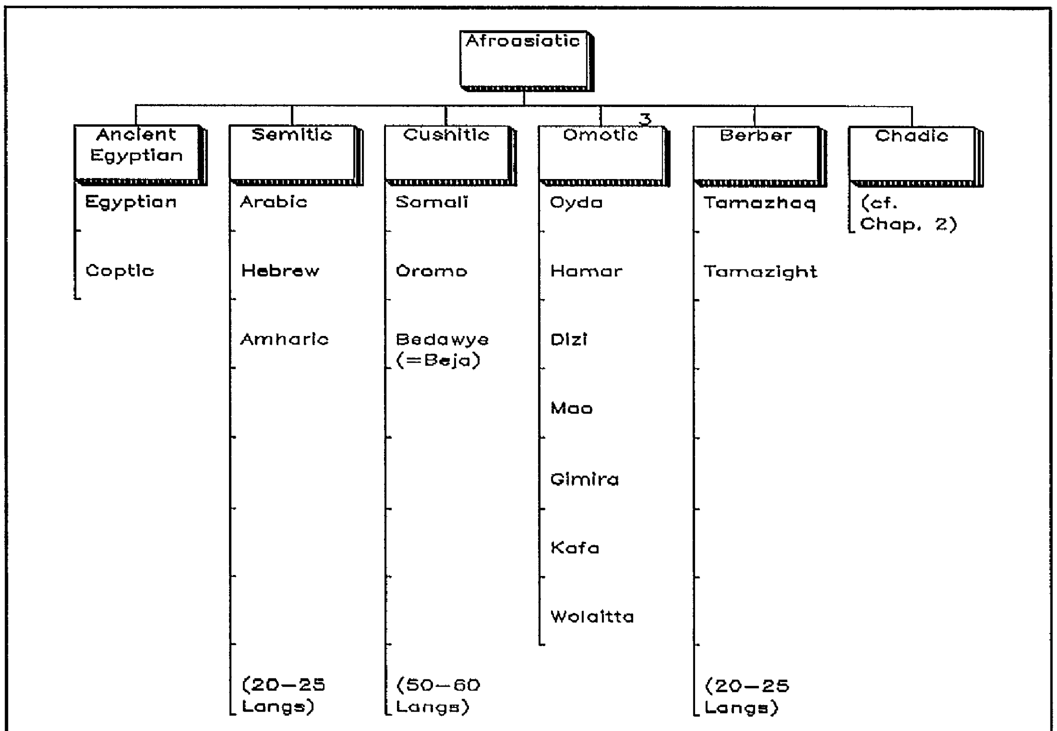


Figure 3.1 Diagram of the AA family (including Omotic). Source: Greenberg (1970) with adaptations.

Chadic-AA Lexicon: Greenberg (1950, 1970).

The following list gives possible cognates for words which contain glottalic consonants in Hausa.

1 Comparative List For /d'/.

| | | | | |
|---|---|---|---|---|
| | 1 | 'four' | | (cf. GR. 1950:61, 1970:57, No. 35) |
| Ch: | Hs. | **pud'u** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| | Bl. | **podo** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| | Mg. | **fodu** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| | Msg. | **podu** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| | Mub. | **fad'a** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| Cush: | Bed. | **fadig** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| | Som. | **afȧr** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| | Or. | **afur** | | (cf. GR. 1950:61) |
| An.Eg: | Eg. | **fdw** | | (cf. GR. 1950:61, 1970:57, No. 35) |
| | Cop. | **ftow** | | (cf. GR. 1950:61) |
| | 2 | 'one' | | (cf. GR. 1950:62) |
| Ch: | Hs. | **d'aya** | | (AH) |
| | Bud. | **kitta** | | (cf. GR. 1950:62) |
| | Bc. | **hido** | | (cf. GR. 1950:62) |
| Sem: | Heb. | **'çhOd** | | (cf. GR. 1950:62) |
| | Ar. | **'aḥad** | | (cf. GR. 1950:62) |
| | Aram. | **ḥad** | | (cf. GR. 1950:62) |

2 Comparative List For /ts/.

| | | | | |
|---|---|---|---|---|
| | 1 | 'sour, sharp' | | (cf. GR. 1970:62, No. 69) |
| Ch: | Hs. | **tsaamii** | | (AH) |
| | Hs. | **yaami** | | (cf. GR. 1970:62, No. 69) |
| | Msg. | **xom** | 'salt' | (cf. GR. 1970:62, No. 69) |
| Cush: | Bj. | **hami** | | (cf. GR. 1970:62, No. 69) |
| An.Eg: | Eg. | **ḥm?(t)** | 'salt' | |

3 Comparative List For /k'/.

| | | | | |
|---|---|---|---|---|
| | 1 | 'bone' | | (cf. GR. 1950:59 and 1970:53, No. 11) |
| Ch: | Hs. | **k'ashii** (< **ḳasii**) | | (cf. GR. 1950:59) |
| | Hs. | **k'asi** | | (cf. GR. 1970:53, No. 11) |
| | Kb. | **kaaso/kaasi** | | (cf. GR. 1970:53, No. 11) |
| | Kb. | **kaaso**, pl. **kaasi** | | (cf. GR. 1950:59) |
| An.Eg: | | | | |
| | Eg. | **ḳs** | | (cf. GR. 1950:59 and 1970:53, No. 11) |
| Ber: | Ber. | **i-xs** (< **i-ks**) | | (cf. GR. 1950:59) |
| | Ber. | **(i)xs** (< **iḳs**) | | (cf. GR. 1970:53, No. 11) |
| | 2 | 'egg' | | (cf. GR. 1950:60 and 1970:56, No. 28) |
| Ch: | Hs. | **k'wai** | | (AH) |
| | Hs. | **k'oy** | | (cf. GR. 1950:60) |
| | Hs. | **k'way** | | (cf. GR. 1970:56, No. 28) |
| | Ng. | **agwOi** | | (cf. GR. 1950:60) |
| | Ng. | **agwoi** | | (cf. GR. 1970:56, No. 28) |
| Ber: | Ber. | **(ti)-glay** | | (cf. GR. 1950:60 and 1970:56, No. 28) |
| | Shl. | **(ta)-glay-(t)** | | (cf. GR. 1950:60 and 1970:56, No. 28) |
| Cush: | Bil. | **kaXaluunaa** | | (cf. GR. 1950:60) |
| | Bog. | **kaXaluunaa** | | (cf. GR. 1970:56, No. 28) |
| | Sa. | **unkualale** | | (cf. GR. 1970:56, No. 28) |
| | Irq. | **qanhi** | | (cf. GR. 1970:56, No. 28) |
| | Km. | **qaluuna** | | (cf. GR. 1970:56, No. 28) |
| | Sa. | **unḳualale** | | (cf. GR. 1950:60) |
| | 3 | 'to weave' | | (cf. GR. 1970:63, No. 76) |
| Ch: | Hs. | **saak'àa** | | (AH) |
| | Hs. | **sak'a** | | (cf. GR. 1970:63, No. 76) |
| | Ang. | **sak** | | (cf. GR. 1970:63, No. 76) |
| | Msg. | **sasaka** | | (cf. GR. 1970:63, No. 76) |
| Sem: | Heb. | **sOkak** | 'weave, cover' | (cf. GR. 1970:63, No. 76) |
| | Ar. | **šakka** | 'cover' | (cf. GR. 1970:63, No. 76) |

It is interesting to see that Hausa ejectives do not seem to correspond in every case to AA /ḳ/, which has reflexes in most branches.

Some comparativists have accepted the importance of vocabulary comparison for establishing linguistic relationships (e.g. Greenberg 1950, 1952, 1970). Others like Cohen (1947) (cf. also N/M (1966), and Newman (1977, and 1978) for Chadic, preferred sound correspondences, while others like Diakonoff (1965) used both lexico-statistics and sound correspondences. Those who objected to the criterion of establishing a linguistic relationship based on sound correspondences did this not because the method was unreliable as such, but because as Hodge (1983:139) put it: "All of the work done on the phylum level has been done with inadequate data".

What we know today about the individual language families as well as their relationship with each other has been increased through the intensive research work of Diakonoff (1965, 1970, and 1974), Bergstraesser (1928 reprinted 1963), Levi and Vida (ed) (1961) for Semitic; Bender (1971, 1975, 1976), Bell (1953), Fleming (1964) and Moreno (1940) for Cushitic; Lukas (1936), Newman (1977b, 1978, 1980) Newman and Ma (1966), Westermann (1952), Westermann and Bryan (1952), Greenberg (1950), Hoffmann (1963) and Jungraithmayr (1970) for Chadic; Abel (1886), Edel (1955) and Gardiner (1957) for Egyptian; and Basset (1952 and 1959) for Berber.

Cohen (1947) classified the languages of the AA phylum based on systematic sound correspondences rather than number of vocabulary correspondences. For the first time, establishment of sound correspondences was considered as a criterion for setting up linguistic relationship between the four main language families stipulated for AA: Semitic, Egyptian, Berber and Cushitic. Even though Cohen was one of the principal founders of AA studies, he rejected the claim that Chadic belonged to AA. The doubt (which one might consider the balanced view of the time) is well expressed by him. He remarked:

> "the question is ... complex and irritating. What must be determined is whether certain of these

> languages or, even the majority of them should not be considered to be members of the Hamito-Semitic family whose definition should be revised in consequence" Cohen (1924:24). Quoted from Greenberg (1950:47).

He therefore excluded Chadic from AA although he has listed a few Hausa (Chadic) words in his comparative study. Not all scholars followed Cohen's ideas, but those who did followed him in excluding Hausa (Chadic) from AA. Some of Cohen's supporters were Rössler (1952), Friedrich (1952) and Leslau (1962).

However, despite the limited data available to Cohen from earlier AA studies, he re-examined the data and presented sound correspondences between the branches. Some 515 comparisons were listed and organized phonetically with the suggested sound correspondences. The work however has been criticised by several writers in the field. Hintze (1951) rejected some of Cohen's etymologies. Leslau (1949) warns of the danger of loan words. This is because according to him Arabic was found to have spread over a wide area where AA languages are spoken. Even Cohen himself has suggested that the parallels which he retained between Hausa and his AA family might well be due to borrowing. Hodge (1971:240) also remarked that: "Few proposed lists have been free of suspects".

Despite a number of false etymologies and inexact reconstructions, on the whole Cohen (1947) demonstrated that the AA family as postulated by the earlier writers (Chadic not included) did indeed constitute a valid linguistic unit. It also served as a basic point of reference for proposed AA cognates and one which demonstrates that considerable phonetic similarity exists between the main language branches of AA. For his contribution, Cohen will be remembered for the rigorous scientific methodology he applied.

Chadic-AA Lexicon: Cohen (1947).

The following list gives possible cognates for words which contain glottalic consonants in Hausa.

1 Comparative List For /b'/.

1 'mud brick' (cf. C. 1947:130, No. 253)

| | | | |
|---|---|---|---|
| Sem: | Ar. | **tuub** | 'brique' |
| | Amh. | **č̣Eḳaa** | 'boue' |
| An.Eg: | Eg. | **ǧb.t** | 'brique crue' |
| Ber: | So. | **idEḳḳi** | 'argile, poterie' |
| Cush: | Bed. | **luk** | 'argile', |
| | | **ɗooO** | 'boue' |
| | Ag. | | |
| | Bil. | **ɗarawḳa** | |
| | Som. | **ɗohb-, ḍoob,** | |
| | | **ɗ̇aȧç** | 'argile, terre à potier' |
| | Or. | **ɗ̇oob,** | |
| | | **ɗ̇oḳe** | 'argile, terre à potier' |
| Ch: | Hs. | **tab'o, čab'i,** | |
| | | **čab'alb'al** | 'boue' |

2 'side of the body' (cf. C. 1947:125, No. 230)

| | | | |
|---|---|---|---|
| Sem: | Heb. | **ḳẹbå(h)** | 'estomac des ruminants (ventricule)' |
| | Ar. | **kibba** | 'ventricule du mouton' |
| | Amh. | **ḳ̇afat** | 'estomac de ruminant' |
| An.Eg: | | | |
| | Eg. | **kOb.t** | 'poitrine' |
| | Cop. | **ėkibe** | 'poitrine de femme, mamelon' |
| Cush: | Ag. | | |
| | Bil. | **ḳabat** | 'estomac de ruminant' |
| Ch: | Hs. | **kwib'i** | 'côté du corps' |

2 Comparative List For /d'/.

1 'taste' (cf. C. 1947:155, No.337)

| | | | |
|---|---|---|---|
| Sem: | Heb. | | |
| | Ar. | **ṭçm** | 'goûter, manger' |

| | | | |
|---|---|---|---|
| An.Eg: | | | |
| | (Eg. | **dp** | 'goûter' ?)' |
| Cush: | Bed. | **tam** | |
| | Ag. | | |
| | Bil. | **taam** | |
| | Sa. | **ṫaçam** | |
| | Af. | **ṭam, tam** | 'manger' ? |
| Ch: | Hs. | **d'and'ana** | 'goûter' |

| | | | |
|---|---|---|---|
| | 2 | 'drip' | (cf. C. 1947:156, No. 341) |
| Sem: | Heb. | **ṭippå** | 'goutte' |
| An.Eg: | Eg. | **dfdf.t** | 'goutte' (and **c̀tf** 'verser' ?) |
| Cush: | Ag. | | |
| | Bil. | **tibb y** | 'goutter' |
| | Sa. | **ṫobb ya** | 'goutter' |
| | Or. | **dimbiba** | |
| | | **č̣oba** | 'goutter' |
| Ch: | Hs. | **d'igo** | 'goutter' |

3 Comparative List For /k'/.

| | | | |
|---|---|---|---|
| | 1 | 'bone' | (cf. C. 1947:124, No. 225) |
| Sem: | Ar. | **ḳaṣṣ** | 'os du sternum' |
| An.Eg: | Eg. | **ḳs** | 'os' (and 'pointe de harpon en os') |
| Ber: | Ber. | **iẖs, igs** | 'os' |
| Ch: | Hs. | **k'ashii** | 'os' |

| | | | |
|---|---|---|---|
| | 2 | 'leg, foot' | (cf. C. 1947:135, No. 268) |
| Sem: | Akk. | **šepu** | |
| | Ar. | **śab** | 'pied' |
| | Amh. | **č̣ammaa** | 'plante' |
| Cush: | Ag. | | |
| | Bil. | **šaanfi** | 'plante, paume' |
| Ch: | Hs. | **tafi** | 'pomme, plante'; |
| | | **k'afa** | 'pied' ? |

3 'to burn' (cf. C. 1947:127, No. 239)

| | | | |
|---|---|---|---|
| Sem: | Akk. | **ḳaraaru** | 'brûler, dessécher' |
| An.Eg: | Eg. | **ḳrr** | 'cuire des pots' |
| Ber: | Ber. | **igar** | 'être sec, desséché' |
| Ch: | Hs. | **k'ona** | 'brûler' |

4 'egg' (cf. C. 1947:116-117, No. 195)

| | | | |
|---|---|---|---|
| Sem: | Ar. | **kayka** | 'œuf' |
| | Amh. | **EnḳwElal** | 'œuf' |
| Ber: | To. | **tekakit** | 'œuf' |
| Cush: | Ag. | | |
| | Bil. | **kagaluuna;** | |
| | Som. | **ogaḥ**, pl. **ukhanti** | 'œuf' also |
| | | **ukkun**, plur. **ukkuman** | |
| Ch: | Hs. | **k'wai** | 'œuf' |

5 'to weave' (cf. C. 1947:139, No.283)

| | | | |
|---|---|---|---|
| Sem: | Heb. | **śakk** | 'sac, grosse toile' |
| | Akk. | **šaḳḳu** | 'sac, grosse toile' |
| An.Eg: | Eg. | **sOḳ** | 'rassembler, contracter' |
| Ber: | Ber. | **asäku** | 'sac double, treillis' |
| Cush: | Bed. | **gas** | 'tisser' |
| | Ag. | | |
| | Bil. | **sak(u), sakŭ,** | |
| | | **zak, sŭnku** | 'tresser' |
| | Som. | **soḣ** | 'tresser' |
| Ch: | Hs. | **sak'a** | 'tisser' |

6 'sand' (cf. C. 1947:100, No. 105)

| | | | |
|---|---|---|---|
| Sem: | Heb. | | |
| | Aram. | **hss** | 'sable, gravier, cailloux' |
| | Ar. | **ḣṡẏ** | 'petits cailloux' |
| | Akk. | **ḫiṣṣu** | 'gravier' |
| An.Eg: | Eg. | **šçy** | 'sable, terrain sableux' |

| | | | |
|---|---|---|---|
| Cush: | Bed. | **haš** | |
| | Ag. | **ašawa** | |
| | Bil. | **ḳušaa** | 'sable' |
| Ch: | Hs. | **k'asa,** | |
| | | **yashi** | 'sable' |

| | | | |
|---|---|---|---|
| | 7 | 'a metal shafted axe' | (cf. C. 1947:126, No. 237) |
| Sem: | Heb. | **kardoom** | |
| | Ar. | **ḳad(d)uum** | 'hache' |
| An.Eg: | Cop. | **ǧaǧomi** | 'houe ?' |
| Cush: | Ag. | | |
| | Bil. | **gǔdub** | 'hache, houe' |
| | Som. | **gudum-o** | 'houe' |
| Ch: | Hs. | **sak'andami** | 'hache' |

| | | | |
|---|---|---|---|
| | 8 | 'testicles' | (cf. C. 1947:127, No. 243) |
| Sem: | Ar. | **kElwa** | 'testicule' |
| | Amh. | **ḳwola** | 'parties génitales (homme)' |
| Ber: | Sou. | **aglay** | (compare tagläit 'œufs') |
| | To. | **tikrarayin** | 'testicules' |
| Cush: | Ag. | | |
| | Bil. | **kǔela** | 'testicules' |
| | Bed. | **ula, wula** | 'testicule', |
| | | **galo** | 'scrotum' |
| Ch: | Hs. | **gwaíwa, golo,** | |
| | | **k'walatai** | 'testicules' |

| | | | |
|---|---|---|---|
| | 9 | 'throat' | (cf. C. 1947:120, No. 206) |
| Sem: | Akk. | **gerru, geeraanu,** | |
| | Heb. | **gårδ(w)n); grgr** | (Akk.**ganguuriitu**, Heb. **gargEro(w)t**, Aram.**gaggartå**); |
| | | grgm | (Ar. **maghribin gErẓum**); |
| | | grç (g.gwrçee) | 'gorge'; |
| | Ar. | **ǧarǧar** | |
| | | **gargar** | 'faire glougou, se gargariser' |
| Ber: | To. | **aaǵurEh** | |
| | Sou. | **agEržum** | 'gorge, larynx' |
| Cush: | Ag. | | |

| | | | |
|---|---|---|---|
| | Bil. | **gǔrgǔmaa** | |
| | Af. | **gǔrdumee** | (Sa. **ɗurgǔma**); |
| | Sa. | | |
| | Af. | **garaç** | |
| | Or. | **gooraw** | |
| | Som. | **gawraç** | 'gorge' |
| Ch: | Hs. | **mak'ogwaro** | 'gorge' |
| | 10 | 'flea' | (cf. C. 1947:116, No. 194) |
| Sem: | Akk. | **kalmatu** | 'ver; pou ?' |
| | Heb. | **knm** | 'insecte piquant' |
| | Aram. | **kalmEta, ḳalmata,** | |
| | Ar. | **ḳml** | 'pou' (Amh. **ḳwEnEčča** 'puce') |
| An.Eg: | | | |
| | Eg. | **ẖnms** | 'mouche' |
| Ber: | Ber. | | |
| | To. | **aaǵurmEl** | 'gros pou du chameau' |
| Cush: | Ag. | | |
| | Bil. | **kEdma** | 'tique' |
| | Sa. | | |
| | Af. | **kilim** | |
| | Som. | **šilin** (pl. **šilm-**), | |
| | Or. | **silma** | 'tique' |
| Ch: | Hs. | **k'uma** | 'puce' |

After the establishment of the fifth branch (Chadic) of AA, the next step was to extend comparisons to more languages of the Chadic family. However due to both restricted interest and restricted knowledge of the languages involved, most AA works have been done comparing Hausa with languages of the other four families of the AA. For example, Hausa and Egyptian (Hodge 1966), Egyptian, Semitic, Cushitic, Berber and Hausa (Calice 1936), Semitic, Cushitic, Berber, and Egyptian plus a few Hausa words (Cohen 1947), Egyptian, Semitic, Cushitic, Berber and Chadic (Hausa) Diakonoff (1965).

The study of Chadic as a group, rather than simply Hausa, recieved its greatest impetus following Nina Pilszczikowa's (hereafter NP) publication of "Le haoussa et le chamito-sémitique à la lumière de l'Essai comparatif de Marcel Cohen" (English translation, "Hausa and Hamito-Semitic, in the light of the comparative essay by Marcel Cohen") in 1960. Her aim was to expand the Hausa data in Cohen's Essai. NP's contribution was in two parts. The first part provides a list of 141 words. The last 12 words of this list (numbers 130-141, pp:124-25) concern the comparisons of Hausa words (No. 134, 137, 138, and 139 contain words from other Chadic languages) with 12 Berber words and their dialect variants. The second part gives a list of 36 comparisons of which 33 of them (No. 1-33) referred to Cohen's comparative list. In the second list, examples were drawn from other Chadic languages either with or without Hausa, and Hausa is represented by 18 words which occur in Cohen (1947).

Three aspects of NP's work are important:

1 The definite inclusion of other Chadic languages (apart from Hausa) which she saw were equally as important as Hausa for comparative AA.

2 She made some useful additions to the comparative list given by Cohen.

3 By providing a fresh perspective, NP's work could be said to stimulate a rethinking of traditional analysis and assumptions long held about Chadic (cf. Carnochan 1977).

On the other hand, one area of her work is questionable: her inclusion of different dialect varieties (cf. e.g. Hausa and Berber) which may not be necessary in a comparative study. Certain comparisons seem to appear too insubstantial to carry much weight as primary evidence of relationship, while in other cases the correspondences in meaning are unsatisfactory. This has been noted by Gouffé

(1969/70:29), who although aware of the preliminary nature of the work, is still critical of the tolerance of inaccuracy inherent in the work.

Chadic-AA Lexicon: Pilszczikowa (1960).

The following list gives possible cognates for words which contain glottalic consonants in Hausa.

1 Comparative List For /b'/.

1 'side of the body' (cf. NP. 1960:113, No. 61)

| | | | |
|---|---|---|---|
| Sem: | Heb. | **ḳẹbå(h)** | 'estomac des ruminants (ventricule)' |
| | Ar. | **ḳibba** | 'ventricule du mouton' |
| An.Eg: | Eg. | **k'b.t** | 'poitrine' |
| | Cop. | **ėkibe** | 'poitrine de femme, mamelon' |
| Cush: | Ag. | | |
| | Bil. | **ḳabat** | 'estomac du ruminant (loan from Tigré?)' |
| Ch: | Hs. | **kwib'i** | 'côté du corps' |

2 'mud for making brick' (cf. NP. 1960:114-115, No.69)

| | | | |
|---|---|---|---|
| Sem: | Ar. | **ṭuub** | 'brique' |
| An.Eg: | Eg. | **ǧb.t** | 'brique crue' |
| Ber: | Sou. | **idEḳḳi** | 'argile, poterie' |
| Cush: | Bed. | **luk** | 'argile' |
| | Som. | **dohb-** | |
| | | **ḋoȯb** | |
| | | **ḍ̇aaE̲** | 'argile, terre à potier' |
| Ch: | Hs. | **tab'o** | |
| | | **čab'i** | |
| | | **čab'alb'al** | 'boue' |
| | | **tuḅali** | 'a ball or brick made of mud' |

| | | | |
|---|---|---|---|
| | 3 | 'rat' | (cf. NP. 1960:119, No. 98) |
| Sem: | Ar. | **fa'r** | |
| | Akk. | **piruruutu** | 'rat' |
| An.Eg: | Eg. | **pnw** | 'rat' |
| Ch: | Hs. | **b'era** | |
| | | **b'ira** | 'rat, mouse' |

2 Comparative List For /d'/.

| | | | |
|---|---|---|---|
| | 1 | 'taste' | (cf. NP. 1960:118, No. 92) |
| Sem: | Ar. | **ṭçm** | 'goûter, manger' |
| An.Eg: | Eg. | **dp** | 'goûter'? |
| Cush: | Bed. | **tam** | |
| | Sa. | **taçam** | |
| | Af. | **ṫam** | |
| | | **ṫam** | 'manger' |
| Ch: | Hs. | **d'and'ana** | 'goûter'? |

| | | | |
|---|---|---|---|
| | 2 | 'drip' | (cf. NP. 1960:118, No. 94) |
| Sem: | Heb. | **ṭippå** | 'goutte' |
| An.Eg: | Eg. | **dfdf.t** | 'goutte' (and **čtf** 'verser'?) |
| Cush: | Ag. | | |
| | Bil. | **tibb y** | 'goutter' |
| | Sa. | **ṫobb ya** | 'goutter' |
| | Or. | **dimbiba** | |
| | | **č̣oba** | 'goutter' |
| Ch: | Hs. | **d'igo** | 'goutte' |

3 Comparative List For /ts/.

| | | | |
|---|---|---|---|
| | 1 | 'to lay out in rows' | (cf. NP. 1960:105, No. 9) |
| Sem: (less Akkadian) | | | |
| | | **'sr** | 'lier' |
| Ber: | Kab. | **arEz** | |
| Cush: | Bed. | **asir** | 'lier, fermer' |
| Ch: | Hs. | **tsara** | |

| | | | |
|---|---|---|---|
| | | **tsare** | 'to lay out in rows, to tie together layers of grass in thatching' |
| | 2 | 'cut in pieces' | (cf. NP. 1960:110, No. 40) |
| Sem: | | **ragaza** | 'frapper de la lance; tuer, égorger' (probable loan from Cushitic) |
| An.Eg: | Eg. | **rh̲s** | 'tuer' |
| Ber: | Ber. | **grs** | 'égorger, couper' |
| Cush: | Sa. | | |
| | Af. | **rahad** | 'égorger' |
| | Ag. | | |
| | Bil. | **ragad** | 'égorger' |
| Ch: | Hs. | **girtsa** | 'to cut in pieces' |
| | 3 | 'shouting, loud call' | (cf. NP. 1960:115, No. 70) |
| Sem: | Heb. | | |
| | Aram. | **šbḥ** | 'crier louange' |
| | Ar. | **sbḥ** | 'crier louange' |
| An.Eg: | Eg. | **sbḥ** | 'crier' |
| Ch: | Hs. | **sowwa** | |
| | | **suwwa** | |
| | | **tsuwa** | 'shouting, crying out' |
| | 4 | 'loins' | (cf. NP. 1960:115, No. 72) |
| Sem: | Ar. | **saraa** | 'dos' |
| | Amh. | **sarasar** | 'colonne vertébrale' |
| An.Eg: | Eg. | **s'** | 'dos, dans le dos de' |
| Cush: | Sa. | **sara** | 'partie arrière' |
| Ch: | Hs. | **tsatso** | |
| | | **tsotso** | 'loins' |
| | 5 | 'the tail hairs of an animal' | (cf.NP 1960:116, No. 76) |
| Sem: | Heb. | **śeçår** | |
| | Ar. | **šaçar** | 'cheveux' |

| | | | |
|---|---|---|---|
| An.Eg: | | | |
| | Eg. | **šny** | 'cheveux' |
| | Cop. | **sorEt** | 'laine' |
| Cush: | Ag. | | |
| | Bil. | **šugur** | |
| | Sa. | **tagar** | |
| | Som. | **ḍogor** | 'cheveux' |
| Ch: | Hs. | **tsagiya** | 'the tail hair of an animal' |

| | | | |
|---|---|---|---|
| | 6 | 'to guard' | (cf. NP. 1960:121, No. 109) |
| Sem: | Akk. | **raaṣu** | 'protéger (fortifier)' |
| | Ar. | **rṣw** | 'fortifier' |
| An.Eg: | Eg. | **rwǧ** | 'être solide' |
| Ch: | Hs. | **ritse** | |
| | | **ratse** | 'to guard, hold (e.g a door)' |

4 Comparative List For /k'/.

| | | | |
|---|---|---|---|
| | 1 | 'sand' | (cf. NP. 1960:108, No. 29) |
| Sem: | Heb. | | |
| | Aram. | **ḥṣṣ** | 'sable, gravier, cailloux' |
| | Ar. | **ḥṣy** | 'petits cailloux' |
| | Akk. | **ḫiṣṣu** | 'gravier' |
| An.Eg: | Eg. | **šçy** | 'sable, terrain sableux' |
| Cush: | Bed. | **haš** | (same form, as loan, in Amharic) |
| | Bil. | **ḳušaa** | 'sable' |
| Ch: | Hs. | **k'asa** | |
| | | **yashi** | 'sable' |

| | | | |
|---|---|---|---|
| | 2 | 'egg' | (cf. NP. 1960:112 No.50) |
| Sem: | Ar. | **kayka** | 'œuf' |
| | Amh. | **EnḳwElal** | |
| Ber: | To. | **tekakit** | 'œuf' |
| Cush: | Ag. | | |
| | Bil. | **kagaluuna** | |
| | Som. | **ogaẖ** (pl. **ukhanti**) 'œuf'; also **ukkun** (pl. **ukkuman**) | |
| Ch: | Hs. | **k'wai** | 'œuf' |

| | | | |
|---|---|---|---|
| | 3 | 'to burn' | (cf. NP. 1960:114, No. 66) |
| Sem: | Akk. | **ḳaraaru** | 'brûler, dessécher' |
| An.Eg: | Eg. | **ḳrr** | 'cuire des pots' |
| Ber: | Ber. | **igar** | 'être sec; desséché' |
| Ch: | Hs. | **k'ona** | 'brûler' |
| | 4 | 'the crop of a fowl' | (cf. NP. 1960:113, No. 56) |
| Sem: | Ar. | **ǧirriyya** | 'gésier' |
| Cush: | Ag.<br>Bil. | **gir**<br>**ǧir** | 'estomac, intestins' |
| Ch: | Hs. | **k'ururu** | 'the crop of a fowl' |
| | 5 | 'bone' | (cf. NP. 1960:113, No. 60) |
| Sem: | Ar. | **ḳaṣṣ** | 'os du sternum' |
| An.Eg: | Eg. | **ḳs** | 'os', 'pointe de harpon en os' |
| Ber: | Ber. | **iẖs**<br>**igs** | 'os' |
| Ch: | Hs. | **k'ashii** | 'os' |
| | 6 | 'the top' | (cf. NP. 1960:114, No. 63) |
| Sem: | Sem. | **ḳulla** | 'cime, sommet de la tête', 'cruche' |
| Ber: | Kab.<br>Sou. | **akErru(y)**<br>**aḳEllal** | 'tête'<br>'tête', 'cruche' |
| Cush: | Ag.<br>Bil. | **agŭar** | 'tête' |
| Ch: | Hs. | **k'oli** | 'the top, summit' |

Another work contributing to the stockpile of literature on PAA reconstructions is Diakonoff (1965) which seeks to establish firmer ground using more critically selected sound correspondences. Diakonoff, who is recognised as one of the principal authorities on Semitic languages, endorsed

Greenberg's classification and accepted the membership of Hausa (Chadic) within the AA family. His book "Semito-Hamitic Languages: An Essay in Classification" deals mostly with morphology, but he also treats phonology although very critical of the amount of data available to him.

Diakonoff sifted through the etymologies proposed by the earlier writers (e.g. Cohen 1947) and presented a newly selected and more expanded list based on the comparison he made between the phonologies of the languages within the AA phylum. Furthermore, he compared the reconstructed forms of the then five branches of AA, namely: ProtoSemitic, ProtoEgyptian, ProtoCushitic, ProtoBerber, and ProtoChadic. He notes that there are certain features which are common to (or, at least, can be easily reconstructed in) the phonological systems of all the AA languages. One of these features is the existence of an "emphatic consonant". Two other features are "voiced" and "voiceless" consonants. According to Diakonoff there is no Semito-Hamitic (AA) language in which the "emphatics" are lost entirely.[4] He therefore added two new phonemes, one is a glottalized /*p'/, and the other is an "emphatic" sibilant /*ṣ/ (cf. Tables 3.1 and 3.2).

| | | | Cushitic (New) | | |
|---|---|---|---|---|---|
| Semitic (Ancient) | Common Berbero-Libyan (New) | Egyptian (Ancient & Middle) | Beja (Bedawye) | Somali | Tchad (New) (Hausa) |
| p'? | - | - | - | - | b' |
| ṭ | ḍ | - | ḍ | ḍ | d' |
| ṣ | ẓ | - | - | - | ts |
| ḳ | - | ḳ | - | ḳ | k' |
| | | | | ḳw | k'w |

Source: Diakonoff (1965:24)

Table 3.1: Phonological Correspondences in Semito-Hamitic (AA) Languages: Correspondences with Hausa (Chadic) Glottalic Consonants

| | Semitic | | | | | | | Cushitic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Akkadian ancient stage | Hebrew middle stage | Aramaic middle stage | Arabic ancient stage stage | South Peripheral ancient | Common Berber | Egyptian | Beja (Bedawye) | Somali | Agau | Tchad (Hausa) |
| p'? | p? | p? | ? | b? | ? | ? | p? | b? | ? | p | b' |
| ṭ | ṭ | ṭ | ṭ | ṭ | ṭ | ḍ/ṭ | d(&t?) | ḍ | ḍ? | ḍ? | d' |
| ṯ̣ | ṣ | ṣ | ṯ̣>ṭ | ẓ | ṯ̣(>s) | t? | ḍ(&t?) | ? | s? | č̣? | c' |
| ḳ | ḳ | ḳ | ḳ | ḳ | ḳ | x̣/ḳ | ḳ | g/k? | ḳ?/g? | ḳ,ḳw | k' |

Source: Diakonoff (1965:26-27)

Table 3.2: Main Phonetic Correspondences in Semito-Hamitic (AA).

Chadic-AA Lexicon: Diakonoff (1965).

The following list gives possible cognates for words which contain glottalic consonants in Hausa.

1 Comparative list for /d'/.

| | | | | |
|---|---|---|---|---|
| | 1 | 'to swallow' | (cf. Dk. 1965:46) | |
| Sem: | | *ṭ'm | 'to swallow, to taste' | |
| Cush: | Sa. | ta'am | 'to swallow' | |
| | Bed. | ṫam | 'to eat' | |
| Ch: | Hs. | d'an-d'ana | 'to taste' | |

| | | | |
|---|---|---|---|
| | 2 | 'four' | (cf. Dk. 1965:49) |
| An.Eg: | Eg. | i-fdw | |
| | Cop. | ftou | |
| Cush: | Bed. | faḍig | |
| Ch: | Hs. | fud'u | |

2 Comparative List For /k'/.

| | | | | |
|---|---|---|---|---|
| | 1 | 'bone' | | (cf. Dk. 1965:43 and 1974:592) |
| Sem: | Heb. | qoos | 'thorn' | (cf. Dk. 1974:592) |
| An.Eg: | Eg. | ks | | (cf. Dk. 1965:43) |
| | | q̇s | | (cf. Dk. 1974:592) |
| Ber: | Ber. | i-XEs | | (cf. Dk. 1965:43) |
| | | i-ghEs | | (cf. Dk. 1974:592) |
| Cush: | Cush. | *m-kkac | | (cf. Dk. 1974:592) |
| Ch: | Hs. | *k'as(i) | | (cf. Dk. 1965:43) |
| | | *kasi | | (cf. Dk. 1974:592) |

After NP (1960) and Diakonoff (1965), the next systematic comparative study of AA was that of Gouffé (1969/70). Taking advantage of earlier works, e.g Cohen (1947), NP

(1960), N/M (1966) and Greenberg (1963), he selected some words from these studies for comparison and provides good equations for them. Gouffé's efforts have resulted in providing a considerable review of literature on comparative AA studies.

Chadic-AA Lexicon: Gouffé (1969/70).

The following list gives possible Hausa words which contain glottalic consonants for comparison with cognates in the references cited above. Only examples from Gouffé are cited to avoid repetition and save space.

1 Comparative List For /b'/.

1 'mud brick'

Ch: Hs. **tàb'oo** 'mud'
**càab'ii** 'sludge'
**càb'àlb'àlii, -oo** 'mud, mire' (cf. G. 1969/70:36-37, C. 17) (see also C. 1947:130, No.253; NP. 1960:114-5,No. 69)

2 'rat'

Ch: Hs. **b'eeraa** 'rat, mouse' (cf. G. 1969/70:38-9, R. 3) (see also C. 1947:167, No.359; NP. 1960:119, No. 98)

3 'rip open'

Ch: Hs. **b'ar̃k-** 'rip open'
**fark-** 'rip, tear open' (cf. G. 1969/70:39, C. 30) (see also C. 1947:169, No. 369)

4 'uncircumcised penis'

Ch: Hs. **lòob'aa** 'prépuce, pénis incirconcis' (cf. G. 1969/70:42, C. 40) (see also C. 1947:191, No. 479)

2 Comparative List For /d'/.

1 'skin an animal'

Ch: Hs. **feed'-** 'écorcher, dépouiller (un animal), vider (une volaille)'
(cf. G. 1969/70:36, C. 13)
(see also C. 1947:124,No. 228)

2 'slit open the front of an animal, bird, person'

Ch: Hs. **fard'-**
**fird'-**
**furd'-** (cf. G. 1969/70:39, C. 27)
(see also C. 1947:168, No. 364)

3 Comparative List For /ts/.

1 'corn, millet'

Ch: Hs. **hatsii** 'sorgho', 'petit mil'
(cf. G. 1969/70:32, C. 4)
(see also C. 1947:102, No. 122)

2 'sour'

Ch: Hs. **tsaamii** 'acidité, goût aigre'
(cf. G. 1969/70:33, C. 5)
(see also C. 1947:103, No. 124)
(see also GR. 1963:62, No. 69)
(see also P. 1955:379)

3 'loins, waist'

Ch: Hs. **tsatsòo** 'région lombaire'
(cf.G. 1969/70:37, C. 19)
(see also C. 1947:135, No.269
NP. 1960:115, No. 72)

4 'urine'

Ch: Hs. **fitsaar̃ii** 'urine, action d'uriner'
(cf.G. 1969/70:40, C. 31)
(see also C. 1947:170, No. 374)

4 Comparative List For /k'/.

1 'calabash'

Ch: Hs. **k'war̃yaa**, pl. **k'òor̃ee/k'òor̃ay**

'récipient hémisphérique en calebasse'
(cf. G. 1969/70:34, C. 8)
(see also H. 1966:46, No. 65)

| | | | |
|---|---|---|---|
| | 2 | 'kidney' | |
| Ch: | Hs. | **k'oodàa** | |
| | | **k'waadàa** | (Katsina and North-West) |
| | | | 'rein' (cf. G. 1969/70:35, C. 9) (see also C. 1947:116, No. 191) |
| | 3 | 'flea' | |
| Ch: | Hs. | **k'ùmaa** | |
| | | **k'umaa** | (North-West) |
| | | | 'tique' (cf. G. 1969/70:35, C. 10) (see also C. 1947:116, No. 194; NP. 1960:111-2, No. 49) |
| | 4 | 'cry out' | |
| Ch: | Hs. | **k'aar̃aa** | 'cri, plainte' (cf. G. 1969/70:36, C. 15) (see also C. 1947:126, No. 235; NP. 1960:114, No. 64) |
| | 5 | 'lie, falsehood' | |
| Ch: | Hs. | **k'ar̃yaa** | 'mensonge; erreur, inexactitude (involontaire)' |
| | | pl. **k'ar̃àyr̃ay** | (cf. G. 1969/70:36, C. 16) (see also C. 1947:126, No. 236) |

Among the contributions to the study of AA etymologies, one may also mention those of Hodge. He wrote three articles, (1966, 1968 and 1969). The 1966 and 1969 papers established the usefulness of setting up sound correspondences as the starting point in comparative study and the 1968 article proposed etymologies with the stress on vowels rather than consonants.

In the 1966 paper, Hodge aimed at integrating the findings on and insights into Chadic languages into the total picture of AA. His study was "based primarily upon the direct comparison of Egyptian and Hausa" (1966:40). See also Vycichl (1934, 1963). Vycichl (1963) equates Hausa /ts/ with Eg. /ḥ/, (p.64), and equates /k'/ with Eg. /q/ and gives the following example:

Hs. **k'àshii** 'bone' : Eg. /q r s/ or /q s/ (p.72).
Quoted from Hodge (1966:42, 55)

Sound correspondences were considered as the primary criteria for setting up the linguistic relationship between the different languages. Given the situation as it was with a very unsatisfactory phonological picture, Hodge therefore sought to provide some evidence to bear on sound correspondences even though the examples are few and drawn from only two branches of the AA phylum.

He therefore set up three correspondences between Egyptian and Hausa for which regular sound correspondences and reconstructed common forms are postulated.[5] The three correspondences he cites are:

1 Egyptian. /3/ : Hausa /r/, or /l/ (53 items).
2 Egyptian. /q/ : Hausa /k'/ (25 items).
3 Egyptian. /ǧ/.[6] : Hausa /ts/ (35 items).

Hodge continued in a series of articles, one of which was specifically concerned about the reclassification of AA based on vocalic quality (cf. Hodge 1968). In 1969, Hodge wrote a follow up article of the 1966 paper. In it, he revised previous estimates and tried to expand his claims about the Egyptian-Hausa correspondence to cover other languages of the AA phylum: Semitic, Cushitic and Berber. His discussion of the consonants was meant to be part of the overall presentation of the AA consonantal system. Although there was no systematic pattern set up, he presented a series of etymologies illustrating the correspondences of Egyptian /ǧ/ to the emphatic sounds found in Semitic, Berber, Cushitic and the glottalized sounds of Chadic.[7] See below for more examples and for the complete list of comparative words see Hodge (1969).

Chadic-AA Lexicon: Hodge (1966, 1968).

The following list gives possible cognates for words which contain glottalic consonants in Hausa.

1 Comparative List For /b'/.

| | | | |
|---|---|---|---|
| | 1 | 'peel' | (cf. H. 1966:45, No. 22) |
| Ch: | Hs. | **b'aarèè** | 'shell, peel' |
| An.Eg: | Eg. | **b 3** | 'hack up, hoe, destroy' |
| | 2 | 'drinking noisily' | (cf. H. 1966:46, No. 60) |
| Ch: | Hs. | **šàrb'aa** | 'noisily drink soup' |
| An.Eg: | Eg. | **š 3 b w** | 'meals' |

2 Comparative List For /d'/.

| | | | |
|---|---|---|---|
| | 1 | 'beat, spin' | (cf. H. 1968:24, No. 12) |
| PAA | | ***kad'-** | |
| Ch: | Hs. | **kad'àà** | 'beat' |
| Cush: | Som. | **gáadayya** | 'attack, ambush' |
| Sem: | Ar. | **qaḍḍa** | 'to crush' |
| | 2 | 'spinning' | (cf. H. 1968:27, No. 1.1) |
| PAA | | ***qad-** | |
| Ch: | Hs. | **kad'iì** | 'spinning' |
| An.Eg: | Eg. | **q d** | 'build, turn' |
| Sem: | Ar. | **qadd** | 'shape' |
| | 3 | 'girls' game of clapping and singing' | (cf. H. 1968:27, No. 3.1) |
| PAA | | ***Xaḍ-** | |

Ch: Hs. **gaad'aa** 'joyous action'

Sem: Ar. **Xaḍḍ** 'fresh, lush'

3 Comparative List For /ts/.

1 'bite' (cf. H. 1966:44, No. 13)

Ch: Hs. **gààtsaa** 'bite off'

An.Eg: Eg. **ι ǧ** 'hack up, destroy'

2 'become well' (cf. H. 1966:45, No. 15)

Ch: Hs. **wartsàkee** 'be all right (e.g be wide awake, be well after sickness)

An.Eg: Eg. **w ǧ 3** 'whole, sound'

3 'scatter, disperse' (cf. H. 1966:45, No. 16)

Ch: Hs. **waatsàà** 'scatter, disperse'

An.Eg: Eg. **w ǧ '** 'send away'

4 'calmness, reflection' (cf. H. 1966:45, No. 38)

Ch: Hs. **nitsu** 'come to one's sense'

An.Eg: Eg. **n ǧ** 'ask'

5 'mountain' (cf. H. 1966:47, No. 93)

Ch: Hs. **tsawnìi** 'mountain'
**tsawoo** 'length, height'

An.Eg: Eg. **ǧ w** 'mountain'

6 'new grass' (cf. H. 1966:47, No. 101)

Ch: Hs. **tsààtsee** 'new grass'

An.Eg: Eg. **ǧ ǧ** 'flowers or the like as ornament'

4 Comparative List For /k'/.

| | | | | |
|---|---|---|---|---|
| | 1 | 'to count' | | (cf. H. 1968:27, No. 1.3) |
| PAA | | ***qid-** | | |
| Ch: | Hs. | **k'idààyaa** | 'count' | |
| An.Eg: | Eg. | **q d t** | 'a measure' | |
| Cush: | Cush. | **kiite** | 'a measure' | |
| Sem: | Ar. | **qidda** | 'ruler' | |
| | 2 | 'become intertwined, entangled' (cf. H. 1966:46, No. 56) | | |
| Ch: | Hs. | **sark'èè** | 'become interlaced' | |
| An.Eg: | Eg. | **s 3 q** | 'pull together' | |
| | 3 | 'finish' | | (cf. H. 1966:47, No. 77) |
| Ch: | Hs. | **k'àrshee**<br>**k'aarèè** | 'end' | |
| An.Eg: | Eg. | **q r s** | 'bury' | |
| | 4 | 'increase, add' | | (cf. H. 1966:46, No. 63) |
| Ch: | Hs. | **k'aaràà** | 'increase' | |
| An.Eg: | Eg. | **q 3 '** | 'tall, exalted' | |
| | 5 | 'apex, top' | | (cf. H. 1966:47, No. 79) |
| Ch: | Hs. | **k'ook'uwaa** | 'apex, top' | |
| An.Eg: | Eg. | **q q** | 'hoopoe' | |
| | 6 | 'grind' | | (cf. H. 1966:45, No. 36) |
| Ch: | Hs. | **nik'àà** | 'grind' | |
| An.Eg: | Eg. | **n q r** | 'sift, sieve' | |

It is striking that Hausa /d'/ usually has an "emphatic" or "glottalized" cognate in other languages; also that /k'/ - difficult to reconstruct for Chadic as a group - so often corresponds to an "emphatic" elsewhere.

To conclude, two independent goals (although often fused together) can be distinguished in the study of AA phylum. One of these is classification; the other is reconstruction of the proto-language.

As regards methodology, Cohen (1947), Hodge (1966, 1968, 1969) and IIIič-Svityč, (1966), have stated their preference for the use of sound correspondences for the purpose of establishing genetic relationships, while Diakonoff has considered both sound correspondences and vocabulary comparison (cf. Greenberg 1970) as primary tools. Using the materials already collected in earlier works (plus a few additions) NP (1960) and Gouffé (1969/70) provided good lists of correspondences in single volumes, thereby making the material easy for reference.

## 3.4 NOTES

1 Data from Cushitic are cited from sources published before the decision to split Cushitic into Cushitic and Omotic. I have therefore retained the classification of the original sources.

2 The term "Hamito-Semitic" or "Semito-Hamitic" was used by Lepsius in the early 1860s. Although it became acceptable at that time, it is an unfortunate label which suggests that the family is divided into a group of "Semitic" and a group of "Hamitic" languages. However the family consists of other languages as well which are coequal with the Semitic languages (cf. Newman 1980). My remarks on the classification of Chadic within AA draw heavily upon Newman (1980).

3 Many thanks to Dr. R.J. Hayward, who brought to my attention that Omotic is now an accepted branch of AA, and also provided the list of languages in this branch.

4 In footnote 16 P.19, Diakonoff states that, "The "emphatic" consonant phonemes find various phonetic realizations: as pharyngealized voiceless consonants (this seems to be the case in most Semitic languages: Dolgopolsky (1977) claimed that the emphatic consonants are glottalized ejectives in Ethopian Semitic languages), or as pharyngealized voiced consonants (in Berbero-Libyan, partly in Arabic), or as voiceless consonants combined with a glottal stop (in the Abyssinian sub-group of Southern Peripheral Semitic, partly in Cushitic and Hausa), as inspiratory consonants (in Hausa, partly), as cerebral (i.e. retroflex) consonants (in certain Cushitic languages). All these articulations have obviously a common origin" (Diakonoff 1965:19). Many other scholars, such as Hodge (1966:41), take the view that the "emphatics" were a later development, the proto sounds being glottalized. Albright attributes this theory to Houpt. (cf. Albright's review of Worrell, Coptic Sounds, Lg 10.221, 1934).

5 Newman (1980) accepts none of Hodge's etymologies. He remarked: "Hodge 1966 for example, presents a list of some hundred etymologies between Hausa and Egyptian, none of which I would consider likely" (NM. 1980:14. fn. 25).

6 Eg. /ǧ/ stands in etymological relationship with several Semitic glottalized series involving /ṣ/.

7 Hodge felt that the existence of the forms in Egyptian justified their presence in other AA languages. Hence it is also possible to project that these forms go back into the ancestor language in AA.

# PART TWO: THE LARYNX AND VOICE MEASUREMENT

# Chapter Four

The Framework of the Larynx: Classification and Definition of Phonation Types.

## 4.1 The Structure of the Larynx.

### 4.1.1 Introduction.

In this section a brief account of the structure of the larynx is given. It is not possible to give a detailed description of its anatomy, for to do this would require a very long discussion beyond the bounds of this thesis. Laver's (1980) description of laryngeal muscles, which sets up a simple schematic diagram for discussing the different locations of the muscles and their behaviour, forms the basis of this account.

The larynx is suspended from the hyoid bone and rests on top of the trachea. It has two main functions, firstly as protective apparatus around the air passage and secondly as a sound producing organ of the vocal apparatus. The larynx consists of two parts within which the control of phonation is exercised. Firstly there is the bony part which consists of three basic cartilages (cf. section 4.1.2). Secondly, there is the softer part which consists of muscles, connecting membranes and ligaments. The muscles help to hold the cartilages in place and can alter the mutual relation between the cartilages. Through their contraction they can raise, lower or rotate these cartilages.

4.1.2 The Laryngeal Cartilages.

To understand the mechanism of the larynx and its vocal function we need to know how the different cartilages are built up and which movements they can perform. Through these cartilages, the position and tension of the vocal folds are regulated. There are three cartilages that form the basic skeleton within which the control of phonation is exercised. They are:

1 Thyroid cartilage
2 Cricoid cartilage and
3 The dual arytenoid cartilages.

See Figure 4.1 which is a schematic diagram of the relative position of these cartilages.

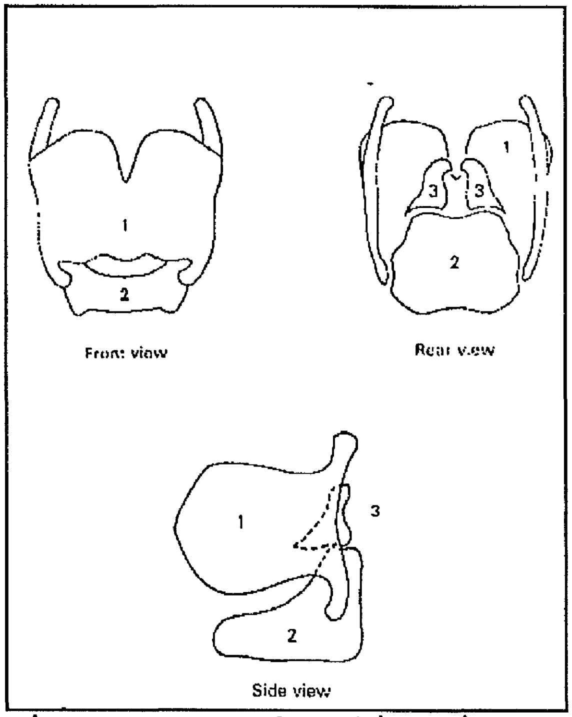



Figure 4.1: Schematic diagram of the principal cartilages.
1 Thyroid cartilage
2 Cricoid cartilage and
3 Arytenoid cartilages

Source: Laver (1980:100).

### 4.1.3 The Thyroid Cartilage.

The thyroid cartilage forms what is called the "Adam's Apple" in the male. It serves as a protective cartilage shielding the front and sides of the larynx from dangerous situations. The thyroid cartilage with its projecting feature, slightly pointed shape and a V-shaped edge sits on top of the cricoid cartilage (cf. Figure 4.2 a). The two legs of the letter V are called the **laminae.** These upward pointed legs are attached to the hyoid bone by means of ligaments (cf. Figure 4.2 b). The muscles which make up the body of the vocal folds and the ventricular folds are attached to the front, interior surface of the thyroid, at the point where the raised edges are fused together (cf. Figure 4.2 c).

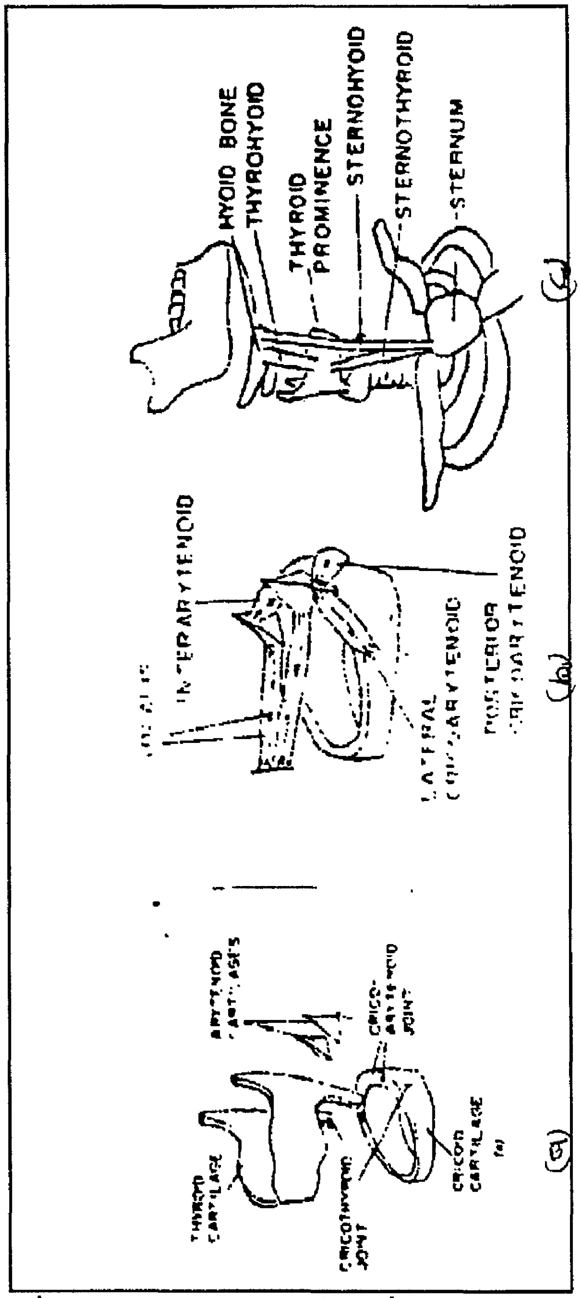



Figure 4.2: showing the cartilages as they are normally joined. Source: Ohala (1978:7-8).

### 4.1.4 The Cricoid Cartilage.

The cricoid cartilage is a structure that looks like a ring with a posterior upright slate and a frontal narrow arch. It lies beneath the thyroid cartilage and rests on top of the trachea. Together, the cricoid and thyroid cartilages form an effective shield for the vocal folds (cf. Figure 4.2 a). On top of the cricoid sit the dual arytenoid cartilages.

### 4.1.5 The Arytenoid Cartilages.

The arytenoid cartilages are small structures, smaller than the thyroid and the cricoid. They look like two pyramids in shape. The pointed heads project towards the hyoid bone. These structures sit on the upper edge of the cricoid at the back (cf. Figure 4.2). They can rotate and swing back and forth to a certain degree, as well as slide from side to side on the cricoid. The muscles attached to the arytenoids control these movements. The posterior ends of the vocal folds are attached to the lower forward ends of the arytenoids, and the posterior ends of the ventricular folds are attached to their apex. The larger extension of the base of each arytenoid cartilage is called the muscular process. This is because three muscles important for the positioning of the vocal folds are attached to it. The muscular process extends posteriorly and somewhat laterally, down and towards the centre (cf. Borden and Harris 1980:77, and Figure 4.3).

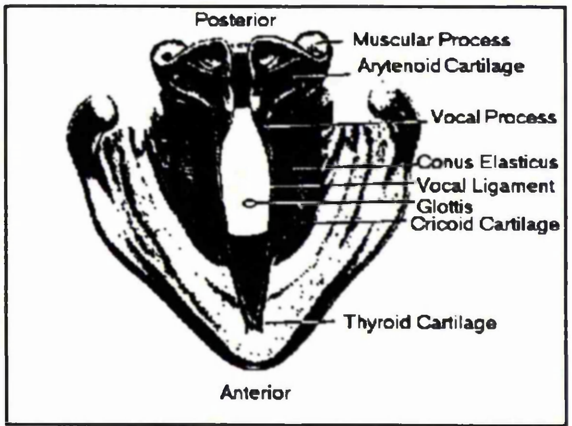



Figure 4.3: The larynx and the fibrous bands (ligaments) and membranes of the larynx. Source: Sonesson (1968:48).

## 4.2 The Structure of the Vocal Folds.

### 4.2.1. Introduction.

We are now in a position to discuss the vocal folds and their various adjustments during speech. The muscles which make up the body of the vocal folds are attached to the front interior surface of the thyroid at the edge where the raised edges are fused together and their posterior ends are attached to the lower forward ends (vocal processes) of the arytenoid cartilages. The vocal process is a small projection pointing anteriorly at the base of each cartilage and is the point of attachment for the vocal ligament with its associated folds. The vocal folds are two three-sided bulges projecting into the larynx. The folds are often described as made up of three constituents:

1 The vocal ligaments which are the upper thickened edges of the conus elasticus membrane rising from the cricoid cartilage.

2 Mucous membrane which covers the folds (Sonesson 1968:60; Borden and Harris 1980:79). More generally, one may distinguish the (inner) muscle from the (outer) mucosa.

3 The vocalis muscles which are the inner parts of the thyroarytenoid muscles attached to the ligament.

In recent publications, Hirano has emphasized the layer structure of the vocal folds. In his anatomical model, the vocalis muscle constitutes the body of the fold while the mucosa is divided into epithelium and lamina propria. The lamina propria is itself divided into superficial, intermediate and deep layers. These differ with regard to the density and relative proportions of elastic and cartilagenous fibres. Together, the epithelium and the superficial layer of the lamina propria, where the fibrous components are loose, constitute the "cover", while the intermediate and deep layers of the lamina propria make up the "transition". Recognition that the cover, transition, and body have different mechanical properties has led to new insights concerning the mechanism of the vocal fold vibration, but we shall not discuss these here (cf. Hirano et al. (1982)).

### 4.2.2 Vocal Fold Adjustments.

#### 4.2.2.1 The Vocal Folds During Phonation.

Vocal fold vibration results from the complex interaction of aerodynamic forces and the elastic properties of the vocal fold tissue. We shall not attempt to survey the current research on modelling vocal fold vibration, which seeks to quantify these forces and explain the nature of their interaction. For an explanation of some approaches see Broad (1979). What follows is a brief account of vocal fold vibration during so-called modal voice.

During the production of modal voice, the vocal folds are in an adducted position (but slightly open, cf. Figure 4.4 a). In this position they vibrate, alternately opening and closing the glottis for very short periods of time. The vocal folds open at the bottom first and the opening then proceeds up to the top of the folds. As the top part opens, the bottom part begins to close as illustrated in Figure 4.5. Each opening and closing action of the vocal folds forms a vibratory cycle.

#### 4.2.2.2 Subglottal Air Pressure.

The elastic properties of the vocal fold tissue will tend to make the folds return to their starting position. The aerodynamic forces are usually discussed under two headings: (1) subglottal pressure and (2) the Bernoulli effect. It is the pressure of air from the lungs which opens the vocal folds during each vibratory cycle. The air pressure built up below the folds must be sufficiently greater than the pressure above the folds. If the air pressure above the folds builds up and becomes equal to the pressure below, as may occur during the production of a voiced stop, the pressure drop across the glottis is lost and voicing ceases.

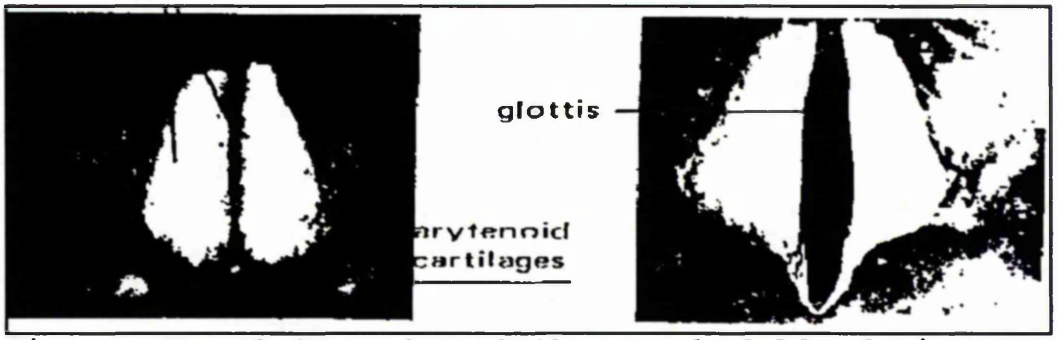


Figure 4.4: Photographs of the vocal folds during (a) voice and (b) voiceless phonation.
Source: Ladefoged (1971:6).

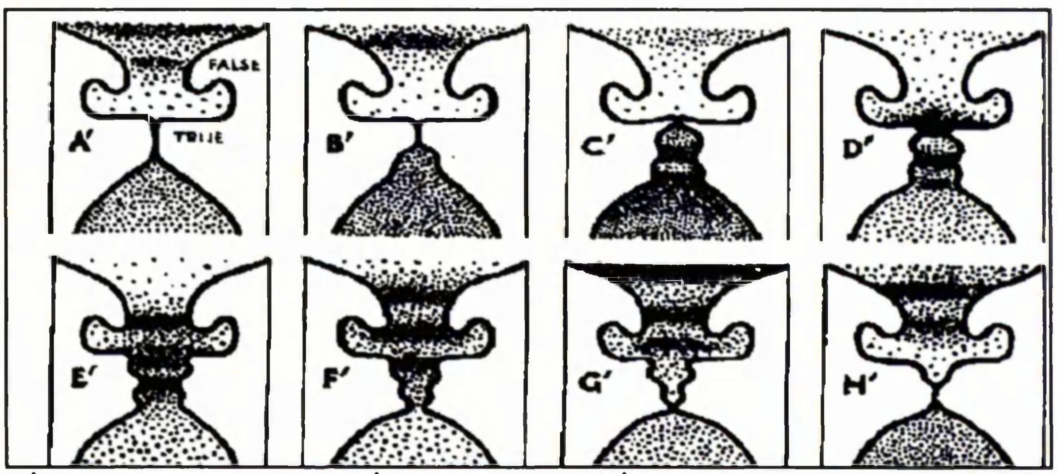


Figure 4.5: Schematic cross-section of the vocal folds during vibration. It can be seen that the folds open and close from bottom to top.
Source: Borden and Harris (1980:83).

### 4.2.2.3 The Bernoulli Principle.

The Bernoulli effect simply means that an increase in velocity will lead to a drop in the pressure applied by molecules of moving gas or liquid. The pressure drop will be perpendicular to the direction of the flow (cf. van den Berg et al. 1957; Borden and Harris 1980:81). See Figure 4.6 which illustrates the increase in velocity within a narrow portion of a passage. The higher velocity creates a negative pressure against the lateral walls which acts to make the vocal folds snap shut.

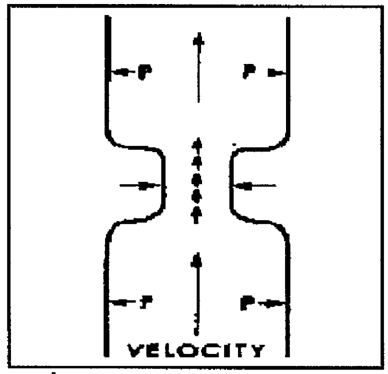



Figure 4.6: Schematic diagram of flow through a constricted passage. In the constriction, velocity is greater, but outward pressure on the sides of the constriction is absent.
Source: Borden and Harris (1980:83).

## 4.3 The Major Intrinsic Laryngeal Muscles.

There are several muscles which effect the movement of the laryngeal cartilages and of the larynx as a whole. Here we shall discuss only briefly the main muscles.

The muscles that relate to the function of the larynx are usually divided into two groups:

1 The intrinsic (internal) muscles, i.e. the muscles adjusting the positions of the laryngeal cartilages, and

2 extrinsic (external) muscles, i.e. the muscles joining the larynx with other skeletal parts of the neck. Our main concern here is with the first group of muscles.

There are five major intrinsic laryngeal muscles (see below) with several other minor ones. Some of these muscles come in pairs. See Figure 4.7 which shows these muscles; cf. Figure 4.8 below which is a schematic representation of these muscles.

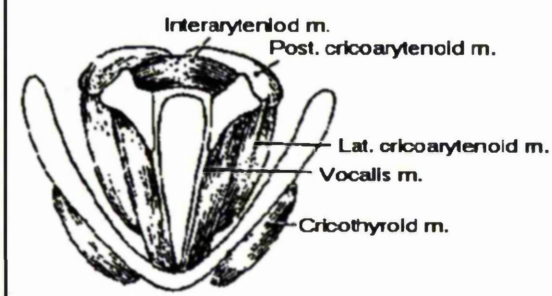



Figure 4.7: The laryngeal muscles.
Source: Hirano (1981:14).

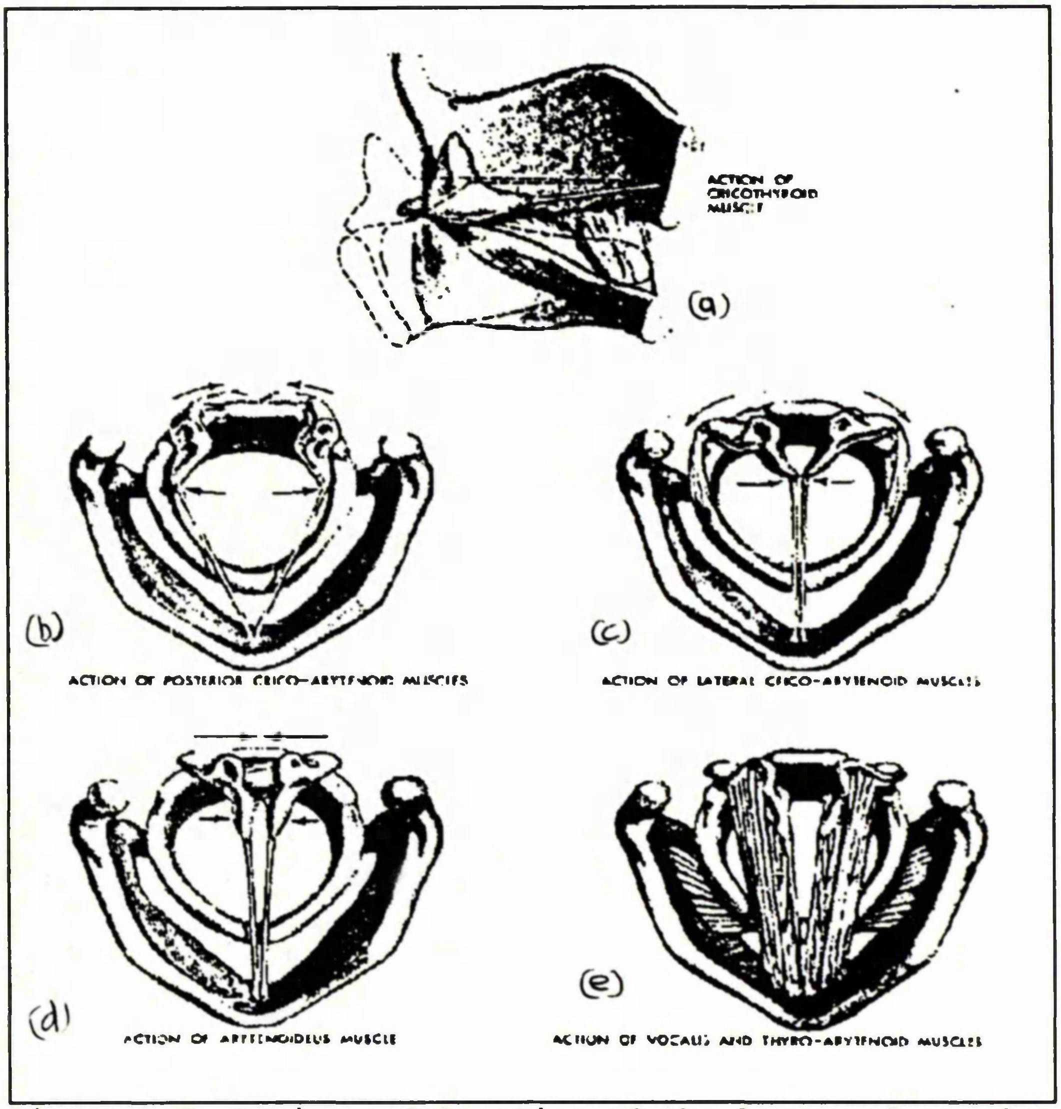


Figure 4.8: Action and location of the laryngeal muscles connecting the cricoid cartilage to the thyroid cartilage and related organs, for comparison with the more schematic diagrams in figures 4.1 and 4.2.
Source: Laver (1980:103).

### 4.3.1 The Cricothyroid Muscles (CT).

The paired cricothyroid muscles lie in the front of the larynx, joining the thyroid and cricoid cartilages. These muscles are responsible for stretching the vocal folds by tilting back the cricoid lamina and the arytenoids by means of a backward rotation in the cricothyroid joint. This is done by pulling up the front part of the cricoid cartilage towards the thyroid cartilage. The effect is to stretch the folds, increasing their longitudinal tension. Other things being equal, this in turn increases their fundamental frequency of vibration (cf. Figure 4.8 a).

### 4.3.2 The Posterior Cricoarytenoid Muscles (PCA) (Opening Muscles).

These muscles have the function of opening the glottis. They lie at the outer rear surface of the cricoid (cf. Figure 4.8 b), and run upwards and to the sides to connect with the muscular processes of the arytenoids. Their contraction pulls the muscular processes in an arc towards the back, and downwards. The effect is to rotate the arytenoids, pivoting outwards the vocal processes, to which the vocal folds are attached. In this way, the vocal folds are drawn apart and the glottis is opened.

#### 4.3.3 Lateral Cricoarytenoid Muscles (LCA) (Closing Muscles).

The actions of these muscles help to close the glottis along its length. These muscles run backwards originating from the anterior upper surface of the cricoid, and attaching themselves on both sides to the arytenoids (cf. Figure 4.8 c). During contraction the muscles offer resistance to the action of the posterior cricoarytenoid muscles by rotating the arytenoid cartilages forward and inward. This action compresses the medial portion of the glottis by bringing the vocal folds together.

#### 4.3.4 Thyroarytenoid Muscle (TA).

The TA muscle lies on the inner side of the thyroid lamina (cf. Figure 4.8 e). It is usual to distinguish two parts: (1) the lower portion, also known as the vocalis (VOC) which is attached to the vocal process of the arytenoid and constitutes the body of the vocal fold, and (2) the upper portion connected to the main part and upper tip of the arytenoid. The TA muscles help to control the position of the arytenoid cartilages relative to the cricoid. When they contract, they draw the arytenoids forward, at the same time tilting them towards the thyroid cartilage. The action of these muscles serves to shorten the folds and is therefore antagonistic to that of the cricothyroid. Contraction of the vocalis also serves to increase the longitudinal tension of the body of the folds.

#### 4.3.5 Interarytenoid Muscle (INT).

Between the two arytenoid cartilages is a stiff band of muscular fibres which runs straight across the posterior face of the arytenoid cartilages. This muscle, which is called the transverse arytenoid muscle, is covered by some muscular fibres which look like the letter X. These muscular fibres are called oblique arytenoid muscles. Together, the transverse and the oblique muscles form the interarytenoid muscle. Contraction of the INT muscle primarily adducts the apices of the arytenoids and brings the back part of them together so that no air can escape. In other words the muscle helps to adduct the vocal folds (cf. Figure 4.8). This INT muscle is considered to be the primary adductor muscle.

4.3.6 Summary.

In general, we may distinguish three main mechanical functions of the intrinsic laryngeal muscles:

1 Opening the glottis (PCA),
2 Closing the glottis (primarily INT and LCA) and
3 Regulating the length and tension of the vocal folds (primarily CT and VOC).

If we think in terms of forces acting on the folds which result from contraction of the intrinsic laryngeal muscles, we may distinguish (following Laver 1980, cf. Figure 4.9):

1 Adductive Tension: This results from contraction of the INT muscles which will bring the arytenoid cartilages together, closing the cartilaginous glottis and hence also the ligamental glottis (cf. Laver 1980:108).

2 Medial Compression: Medial compression is a composite adductive product of the action of a number of muscles, including the lateral cricoarytenoids and the lateral parts of the thyroarytenoids. The idea of medial compression overlaps that of adductive tension (cf. van den Berg (1968)). Laver (1980:108-109) distinguishes the two as follows: medial compression serves to close the ligamental glottis while adductive tension is applied to the arytenoid cartilages and serves to close the cartilaginous glottis.

3 Longitudinal Tension: This is achieved by the contraction of the vocalis and/or the cricothyroid muscles.

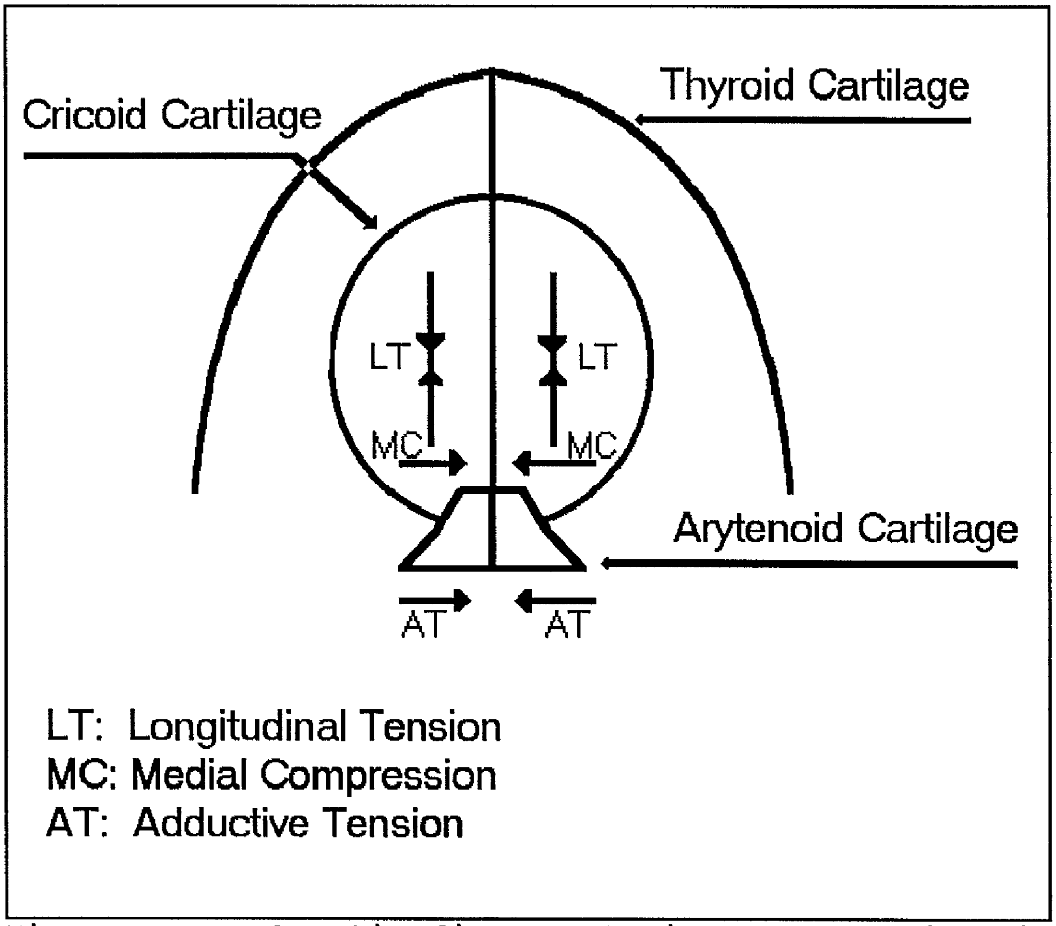



Figure 4.9: Schematic diagram showing the relationship between the three laryngeal cartilages and the three forces acting on them.
After Laver (1980:109).

## 4.4 Classification and Definition of Phonation Types.

### 4.4.1 Introduction.

> "By phonation we mean any relevant activity in the larynx which is neither initiatory nor articulatory in function .... Phonatory activities are described chiefly in terms of postures and movements of the vocal folds. These may be widely separated, as for <u>voiceless</u> phonation (such as [f], [s], [p] (cf. Figure 4.4), or they may be brought together to form a narrow chink, without actually vibrating, as for whisper ... and so on" Catford (1977:16).

Thus, a variety of linguistic contrasts such as voiced/voiceless, aspirated/unaspirated, creaky/non-creaky, all based on differences in laryngeal activity, may be considered phonation type contrasts. The choice of a general framework for the description and classification of phonation types is an important issue in phonology as well as in phonetics.

In the present thesis, we are not concerned with more general issues of classification. We shall not take up the question of whether phonation types should be classified using one dimension only (cf. Ladefoged's degree of stricture scale, Ladefoged (1970, 1971 and 1973) and Abercrombie (1967)), or two dimensions (cf. Halle and Stevens' proposals concerning degree of stricture and stiffness, (Halle and Stevens (1971); Lindqvist's proposals concerning degree of stricture and tension, Lindqvist (1969)); or Catford's proposals concerning degree of stricture and location, (cf. Catford (1939, 1964 and 1977) and Laver (1975 and 1980)).

At a lower level, phoneticians (and phonologists) commonly distinguish three types of voicing: (1) "modal" or "normal" voice, (2) "breathy" voice and (3) "creaky" voice.

### 4.4.2 Modal Voice.

We have given a brief description of the mechanism of modal voice above (cf. section 4.2.2.1). This is sometimes called simply "voice" (cf. Ladefoged 1971:8), or "chest voice" (cf. van den Berg 1968:297; Fourcin 1974a; Abberton 1976:51; Catford 1977), or "neutral mode" (cf. Laver 1980:94). The term "modal" (cf. Hollien 1974:126; Howard 1988; and Colton 1988:208) is used because this type of vibration is the most common (the mode) in (Western) speaking and singing. Laver considers it to be the "neutral mode" because "the vibration is periodic, efficient, and without audible friction" (cf. Laver 1980:94). The mechanism of modal voice is reasonably well agreed.

Commenting on the mechanism of modal voice van den Berg writes:

> "This register is characterized by large amplitudes of the vocal folds at low pitches. This requires small passive longitudinal tensions in the vocal ligaments. The minimal values of the interarytenoid contraction, and medial compression are small. The vocal folds are short and thick" (cf. van den Berg 1968:297).

In a somewhat similar way, Ladefoged describes this state of the glottis as that in which the vocal folds are adjusted so that they are almost touching over their entire length with vibration occurring periodically due to pressure built up below them (cf. Ladefoged 1971:8).

Catford says there is

> "periodic vibration of the vocal folds under pressure from below ... glottal area is small (and) the general aerodynamic picture is of a series of high-velocity jets shot into the pharynx. Acoustically, periodic sound of fundamental frequency within the range of 70 cps

to 1100 cps" (Catford 1964:31).

In a later book he gives further details, stating that voice is produced with the

> "glottis closed, and vocal folds subjected to varying degrees of tension, such that they vibrate (at volume-velocities from about 50 cm3/s upwards and from about 2 to 3 cmH2O up to about 30 cmH2O subglottal pressure), emitting periodic high velocity puffs of air, generating the periodic sound known as voice: ... characteristically occuring with low frequencies from about 60 to 150 or so Hz" (Catford 1977:100).

Hollien (1974) makes the following comment about his choice of the term "modal voice" and goes on to define it. He remarked:

> "The modal register is a term I have used for some years; originally, I favoured the term "normal" to identify this register. However, as van den Berg (1966) pointed out, the use of the label "normal" would imply that the other registers were abnormal and, of course, his logic is correct. Accordingly, the modal register is so named because it includes the range of fundamental frequencies that are normally used in speaking and singing (i.e. the mode). It is a rather inclusive term and many individuals - especially workers in vocal music - would argue that this entity actually constitutes a set of registers or sub-registers including either two (chest and head) or three (low, mid and high) separate entities. I concede the tradition of such an approach but, as may be seen, I have yet to find reasonably convincing evidence that such sub- registers do indeed exist" (Hollien 1974:126).

For Colton (1988), modal voice

> "refers to that range of frequencies used most of the time during speaking and singing, usually from about 90 Hz to about 250 Hz in the male voice, although the span is somewhat larger for singers" (Colton 1988:209).

Having outlined the characteristics of modal voice, we shall now give an overview of previous descriptions of creaky voice and breathy voice.

### 4.4.3 Creaky voice.

In the phonetic literature creaky voice is sometimes called "vocal fry" (cf. Moore and von Leden 1958, Hollien et al. 1966 and Moore 1971), "glottal fry" (cf. Catford 1977), "laryngealization" (cf. Ladefoged 1968), "glottal trill" (cf. Pike 1943), "glottalization"[1] (cf. Carnochan 1952), or "pulse register" (cf. Hollien (1974) and Colton (1988)). Laver uses it as a "cover term" not only for laryngeal activity but also for the associated supralaryngeal factors (cf. Laver 1980). The widely used label for this quality "creaky voice" is chosen in this study. The following is a brief survey of some of the definitions of creaky voice.

In his book Phonetics, Pike (1943) uses the articulatory term "trill" to refer to a type of phonatory stricture. Several types of trills are distinguished, one of which is "vocal trill", which Pike defines as the sound

> "often heard in the speech of people who are talking in a tone of voice very low as compared with normal style; ... (or) the attainment of the sound made by 'singing two notes lower than you can' (Pike 1943:126).

He also notes that two types of "vocal trill" are distinguished: (1) "glottal trill" (which is synonymous with "creak") and (2) "laryngealization" (cf. Pike 1943:127), which is equivalent to what Catford and Laver call "creaky voice". As regards "creak" Pike says that it is "analogous to the slow movement of a stick on a picket fence" (Pike 1943:127); and as regards creaky voice, he says

> "In these sounds the separate percussions of the glottal trill are audible while at the same time regular voice vibrations add their characteristic sound" (Pike 1943:127).

Pike cites English as one language in which this phenomenon may be observed.

Catford (1964) distinguishes between "creak" (which Pike calls "glottal trill" (cf. Pike 1943 :127) and "creaky voice". As regard "creak", he remarked:

> "The precise physiological mechanism of creak is unknown, but only a very small section of the ligamental glottis, near the thyroid end is involved. The auditory effect is of a rapid series of taps, like a stick being run along a railing" (Catford 1964:32).

In (1977) he adds that, in creak, the vocal folds are in close contact (cf. Fig. 4.10),

> "but not much tensed, and air escapes in small periodic burst through a very small aperture near the forward end of the vocal folds. The subglottal pressure is very low, and so too is the volume - velocity being of the order of 12 $cm^3/s$ up to a maximum of about 20 $cm^3/s$" (Catford 1977:98).

As regards creaky voice, Catford considers that the exact mechanism of producing it is not clear, but says it is certain that a combination of voice and creak occur, "with very relaxed vocal folds" (Catford 1977:100).

For Hollien and his co-workers, "creaky voice" is a distinct "vocal register" at the lower end of the (spoken) pitch range. Contrasting it with "modal voice", they specify the following details:

1 the vocal folds when adducted are relatively thick and apparently compressed,

2 the ventricular folds are somewhat adducted also, and

3 the inferior surfaces of the false folds actually come into contact with the superior surfaces of the true vocal folds.

Figure 4.10: The vocal folds during creaky voice. Source: Ladefoged (1971:6).

Thus, an unusually thick, compact (but not necessarily tense) structure is created prior to the initiation of the phonation. Under this condition the "basic laryngeal adjustments may serve to produce a damping of the vocal fold movement." Commenting on the aerodynamic factors involved they suggested that the vibration of the vocal folds is "initiated and maintained by relatively low subglottal pressure; that air-flow, if measured, would be considerably less than for other phonational events" (Hollien et al. 1966:247).

Abercrombie (1967) defines creaky voice as one

> "in which the cartilage glottis is vibrating very slowly, while the rest of the glottis is in normal vibration (it is a characteristic of the accent of England known as 'Received Pronunciation' to use this register when the pitch of the voice falls below a certain point)" (Abercrombie 1967:101)

Moore (1971) also takes note of the role played by the ventricular folds in the production of creaky voice. On the basis of frontal stroboscopic laminograms he suggests that,

> "'vocal fry' (creaky voice) may ... be produced when the mass of the vibrators is increased by

> the collaboration of the ventricular folds. These structures appear in x-ray photographs to combine the ventricular folds functionally with the vocal folds to form massive bilateral vibrators that move with relatively small amplitude. It is presumed that this mechanism is capable of both impeding the flow of air, even when there is considerable pressure, and of releasing a series of pulses in which the channel is open for relatively short portions of the cycles" (Moore 1971:72, quoted from Laver (1980:123).

Laver (1980) reports Hollien and Wendahl (1968) as saying that the primary criterion which must be met in order for a signal to be perceived as creak is a "train of discrete excitations or pulses produced by the larynx" (cf. Hollien and Wendahl 1968:506). According to Laver "pulses" means "any of a variety of glottal waveforms of brief duration separated by varying periods of no excitation" (Laver 1980:124).

Ladefoged has used two terms, "laryngealization" and "creaky voice". He has given definitions of laryngealization in several publications. In A Phonetic Study of West African Languages (1964, 2nd ed. 1968), it is defined as a state of the glottis in which

> "there is a great tension in the intrinsic laryngeal musculature, and the vocal cords no longer vibrate as a whole. The ligamental and arytenoid parts of the vocal cords vibrate separately, sometimes almost exactly 180 degrees out of phase with one another, one end opening, as the other is closing. This produces an apparent increase, often an approximate doubling, of the rate of occurrence of glottal pulses" (Ladefoged 1968:16, cf. Fig. 4.10).

In a later work Preliminaries to Linguistic Phonetics the definition is very different:

> "In this type of phonation the arytenoid cartilages are pressed inward so that the posterior portion of the vocal folds are held together and only the anterior (ligamental)

> portions are able to vibrate. The result is often a harsh sound with a comparatively low pitch" (Ladefoged 1971:14-15).

Creaky voice is distinguished from laryngealization in that it involves "slight (but not complete) relaxation of the pulling together of the arytenoids" with "a larger-portion of the glottis vibrating" (Ladefoged 1971:18). Even though Ladefoged had distinguished two categories, laryngealization and creaky, as separate entities on a continuum of glottal stricture, he adds that such a distinction is often not necessary for any linguistically motivated theory. As in the case of so many other phonetic oppositions there is an infinite gradation between the parameters (cf. Ladefoged 1971:15).

One question which arises is the relationship between creaky voice and fundamental frequency. Ladefoged (1973) argues that pitch and glottal stricture are often clearly independent features and that most glottal strictures (including creaky voice) can occur on a wide range of pitches. There are, he claims, obvious physical reasons which allow creaky voice to occur in high pitches. The major mechanism for varying the pitch of the voice is by stretching the vocal folds in a forward-backward dimension, resulting from the various movements of the thyroid and cricoid cartilages due to the contraction of the cricothyroid muscles (see section 4.3.1). Changes in phonation type (which Ladefoged associates with glottal stricture) result from the changes in the position of the arytenoid cartilages. Thus:

> "... the coming together of the arytenoids and the movements of the thyroid cartilage that stretch the vocal folds are independent laryngeal gestures, so that it is quite possible for creaky voiced sounds to occur on any pitch" (Ladefoged 1973:75).

Earlier claims in the literature say that creakiness can only occur with low pitch. In languages such as Korean, Hausa, Bura, Margi and Mpi creaky voice is thought to be produced by bringing the arytenoid cartilages closer to each other (cf. Ladefoged 1971 and 1983). This action forces the arytenoids to move forward and, as a result, the vibrating parts of the vocal folds remain less stretched. But when the forces acting on the thyroid cartilage make it move forward, the vocal folds are stretched, raising the pitch. This kind of interaction is possible on high pitch syllables.

Another aspect of creaky voice is the characteristic pattern of its cycles of vocal fold vibration.

Fry (1979) said that creaky type of phonation

> "is characterized by interspersion of larynx cycles of abnormally long duration; sometimes such cycles alternate with cycles of shorter period, so that there is short cycle followed by a long cycle, followed by a short cycle and so on" (Fry 1979:68).

Fourcin and Abberton (1971), Fourcin (1974a & 1981), Abberton and Fourcin (1984) and Howard (pers comm.) considered creaky voice together with other voice qualities in normal male speech in terms of the typical laryngograph output (Lx) associated with each and the synchronous speech pressure waveform (Sp) from a microphone. They agree that the main characteristic pattern emerging from the examination of the Lx waveforms indicates

> "vocal contact-separation sequences in which a small peak precedes a larger peak both occuring with considerable temporal irregularity. The smaller peak has a relatively slower onset than the longer and the width of the longer peak indicates a very long closure duration" (Fourcin 1981:118).

However there are times when the "smaller peaks may occasionally be missing", then the perceptual character of the sound changes" into a vocal fry (cf. Fourcin 1981:118).

In an earlier paper Fourcin described the perceptual quality of creaky voice as that which is "characterized by its low irregular pitch and sharply defined vocal tract resonances" (Fourcin 1974a).

There is considerable variation in the above definitions, but it is possible to distinguish two general approaches. The first begins with a definition of "creak" or "glottal trill", a very low-pitched vibration in which individual pulses are audible. "Creaky voice" is then defined as creak + voice. The second sees the chief characteristic of creaky voice as the pressing together of the arytenoid cartilages so that only the anterior portion of the folds may vibrate. According to this definition, creaky voice is clearly the opposite of breathy voice, during which the arytenoids do not close completely.

#### 4.4.3.1 Linguistic Function of Creaky Voice.

Creaky phonation has been shown to play an important role in a phonological analysis. A well-known example is Danish. Abercrombie cites the two words **hun** "she" vs. **hund** "dog" where **hund** is pronounced with an added creaky voice (cf. Abercrombie 1967:101).

Ladefoged has given many examples of languages in which creaky voice is phonologically contrastive. In Ladefoged (1983) he states that laryngealized sounds in different languages may vary in the degree of adduction of the vocal folds and that they may occur on any pitch. For example, in Mpi, a Tibeto-Burman language laryngealization may occur with a high degree of vocal fold adduction on any pitch. Mpi has six tones each of which may occur with plain or laryngealized phonation. The tones are low, mid and high and each of these tones has a corresponding contour tone. We have the following examples for the syllable **[si]**.

| | | plain | laryngealized |
|---|---|---|---|
| 1 | low contour | 'to be putrid' | 'to be dried up' |
| 2 | low | 'blood' | 'seven' |
| 3 | mid contour | 'to roll' | 'to smoke' |
| 4 | mid | (a colour) | (classifier) |
| 5 | high contour | 'to die' | (man's name) |
| 6 | high | 'four' | (man's name) |

Source: Ladefoged (1983:353).

In Nuer, a Nilotic language spoken in the Sudan, a lesser degree of laryngealization occurs on vowels. In this language there are contrastive vowel harmony sets, one being slightly laryngealized the other being slightly breathy (murmured). A contrast between slightly laryngealized and slightly breathy vowels is also reported in Bruu, a Mon-Khmer language, in such words as:

| laryngealized | | slightly murmured | |
|---|---|---|---|
| **ki:t** | 'fear of crowds' | **ki̤:t** | 'to sharpen' |

(The ̤ under the vowel denotes the breathy nature of the vowel)
Source: Ladefoged (1983:353).

Other languages cited by Ladefoged are Korean and Chadic languages including Hausa (the subject of this study), Margi and Bura. In these languages there are laryngealized consonants. In Korean strong stops for example, a slight degree of laryngealization may occur in such words as:

| laryngealized | | plain | |
|---|---|---|---|
| **p*ul** | 'horn' | **pul** | 'fire' |

(The asterisk * denotes the fortis nature of the stop).
Source: Ladefoged (1983:354).

In Chadic languages, laryngealization occurs not only in stop consonants but also in semi-vowels. Ladefoged cites the following examples.

Contrast involving laryngealized consonants and semi-vowels in Hausa, Bura and Margi.

Hausa

| | laryngealized | | plain | |
|---|---|---|---|---|
| 1 | **d'afàa** | 'stick onto' | **dafàa** | 'cook' |
| 2 | **fad'àa** | 'quarrel' | **faadà** | 'court of chief' |
| 3 | **'yaa'yaa** | 'children' | **yaayuu** | 'brothers and sisters' |

Bura

| | laryngealized | | plain | |
|---|---|---|---|---|
| 1 | **w'ala** | 'big' | **waskì** | 'each' |
| 2 | **j́ahà** | 'doctor' | **jà** | 'give birth' |

Source: Ladefoged (1983:354).

Margi

| | laryngealized | | plain | |
|---|---|---|---|---|
| 1 | **b'àb'àl** | 'hard' | **babal** | 'open place' |
| 2 | **d'àd'àho** | 'bitter' | **dàlma** | 'big axe' |
| 3 | **j'à** | 'thigh' | **jà** | 'give birth' |

Source: Ladefoged (1971:15).

In English, creaky voice is used paralinguistically, to signal the completion of an utterance, and when used throughout an utterance, it is said to signal bored resignation (cf. Ladefoged (1968), Laver (1976:351)). Laver (1980:126) also reports Brown and Levinson as saying that in Tzetal, a Mayan language, creaky voice is used paralinguistically "to express commiseration and complaint, and to invite commiseration" (Brown and Levinson 1978:272).

Trudgill showed, in an investigation of the speech of the East Anglian City of Norwich that, the articulatory patterns of working-class speakers, compared with those of middle-class speakers, are marked by the habitual use of a number of laryngeal settings. These include creaky phonation, a high pitch range, a frontal and lowered tongue position, "... and a relatively high degree of effort and muscular tension throughout the speech production apparatus" (Trudgill 1974:188).

He goes on to say that,

> "perhaps the single socially most significant feature of linguistic differentiation in Norwich is the type of voice quality produced by the particular type of setting employed by the speaker. It is in any case this feature which most clearly distinguishes WC from MC speakers" (Trudgill 1974:190-191).

Similarly, Esling (1978) has reported that in Edinburgh social class correlates with laryngeal setting, in that higher social status corresponds to a greater incidence of creaky phonation, and lower status to a greater incidence of whisperiness and harshness.

### 4.4.4 Breathy Voice.

In the literature a variety of terms for this phenomenon are used, including "murmur" (cf. Pandit 1957, Ladefoged 1971), "breathiness" (cf. Zimlin 1964, Laver 1980) or "breathy voice" (cf. Catford 1977). For some authors, these terms refer to two distinct phonation types, while to others they are synonymous.

Ladefoged (1964, 2nd ed. 1968; 1971 and 1975) describes several states of the glottis which he claims are linguistically significant. He regards these as points on a continuum of glottal stricture ranging from glottal stop to voicelessness. In his Preliminaries to Linguistic Phonetics (1971), Ladefoged lists murmur and breathy voice as distinct states. Murmur is characterized by "a widening of the glottis, particularly between the arytenoids" so that only the ligamental (anterior) portion of the vocal folds vibrates. This is arbitrarily distinguished from "breathy voice" "in which there is even greater rate of flow through the glottis" (Ladefoged 1971:18, cf. Figure 4.11).

In a later book, Ladefoged (1975) gives up the distinction between murmur and breathy voice. He now recognizes a single type which may be produced by a number of diverse articulatory strategies possibly involving different muscular activities. The two main types of laryngeal adjustments that will produce breathy voice are:

1 Breathy voice occurs when the vocal folds are slightly apart: they can still vibrate, but at the same time a great deal of air passes through the glottis.

2 Breathy voice sounds are sometimes made with the glottis fairly wide apart at the end and a chink between arytenoids (cf. Ladefoged (1975:122-3, and Figure 4.11).

Figure 4.11: The vocal folds during breathy voice. Source: Ladefoged (1971:6).

Auditorily Ladefoged says the quality perceived for breathy voice is the quality of the English sound /h/ between vowels (cf. Ladefoged 1971). In Ladefoged (1983), he states that, because the vocal folds are vibrating without coming completely together, the higher airflow creates turbulence which causes more noise excitation of higher frequencies (cf. Ladefoged 1983:357).

To illustrate these phenomena, Ladefoged cites examples from Indo-Aryan languages (Hindi, Bihari, Marathi, Bengali, Assamese, Gujarati, Sindhi and Marwari) and African languages (Shona, Tsonga, Ndebele and Zulu). In these languages different laryngeal configurations are said to be used to produce breathy voice. Breathy voice in the Indian languages

> "is distinguished by a different adjustment of the vocal folds in which the posterior portions (between the arytenoid cartilages) are held apart, while the ligamental parts are allowed to vibrate. There is a high rate of flow of air out of the lungs during these sounds" (Ladefoged 1971:12).

As regards the southern Bantu languages, he says "during breathy (murmured) voice sounds the vocal folds seem to me to be held slightly closer together than in the Indian languages, so that there is more voice and less breath escaping" (Ladefoged 1971:13-4).

Catford (1964 and 1977) distinguishes between breathy voice and whispery voice. The two categories are said to differ in terms of laryngeal configuration, aerodynamic factors and auditory quality associated with their production.

Commenting on breathy voice which for him is breath plus voice, he says that the

> "glottis (is) relatively wide open: turbulent air flow as for "breath" plus vibration of the vocal

> folds. The folds do not meet at the center line: they simply "flap in the breeze" (Catford 1964:32).

In a later book Catford (1977) he expands this definition slightly and says

> "the glottis is narrowed from its most open position, but not narrowed enough to generate whisper, that is, it is still at considerably more than 25 percent of its maximal opening, probably, in fact, around 30 to 40 percent. The vocal folds are vibrating, but without ever closing or, indeed, coming any where near closing. They simply "flap in the breeze" of the high-velocity airflow. The laminal volume-velocity for the production of breathy voice is of the order of 90 to 100 $cm^3$/s: more commonly, however, it is much faster, around 900 to 1000 cm/s" (Catford 1977:99).

Auditorily, he says this phonation type has the auditory effect of the phonation type of voiced /h/ (cf. Catford 1977:99). Whispery voice, on the other hand, is produced with a distinct glottal configuration. There is a

> "somewhat relaxed vocal folds vibrating to generate voice, with continuous, simultaneous, richly turbulent escape of air through a chink, generating whisper" (Catford 1977:101).

Catford further distinguishes two types of whispery voice as follows:

1 Normal (fully closing) voice-vibration "up front" with a space for escape of whisper air between the arytenoid cartilages. He defines it as one in which

> "the arytenoid cartilages are somewhat separated, so that there is whisper - generating chink at the posterior end of the glottis, while the vocal folds, forward from the vocal processes are vibrating normally - that is, with a normal cycle of closed and open phases" Catford 1977:99).

2 Full glottal. In this type the vocal folds are relaxed,

> "never closing completely so that there is always a chink for escape of whisper-air somewhere along their length. Air-flow much slower than for breathy voice - about 60 to 300/400 $cm^3/s$" (Catford 1977:101).

This particular type has often been called "breathy voice" wrongly (according to Catford 1977:101), or "murmur" (Gray 1939, Pandit 1957 and Ladefoged 1971).

Laver (1980) quotes Zémlin (1964:165) and Fairbanks (1960). The first of these considers that breathiness is most commonly associated with a persistent chink at the back (cartilaginous) end of the vocal folds. Fairbanks, however, sees breathiness as resulting from failure of the folds to close completely during each cycle.

For Laver himself (1980), "breathiness" is a quality which is quite often heard as a modification of modal voice, giving breathy voice. Like Catford, Laver distinguishes between breathy and whispery voice. He describes the laryngeal configuration for breathy voice as follows:

> "...the mode of vibration of the vocal folds is inefficient, and is accompanied by slight audible friction. Muscular effort is low, with the result that the glottis is kept somewhat open along most of its length, and the folds never meet on the mid-line. Because each closing movement of the folds tends to be abortive, the lessened glottal resistance leads to a higher rate of air-flow than modal voice" (Laver 1980:132).

He goes on to say,

> "The muscle tension adjustment necessary for breathy voice can be seen as involving minimal adductive tension and weak medial compression, just sufficient to allow aerodynamic forces in the comparatively large volume of transglottal

> airflow to superimpose on the outflowing air a very inefficient vibration of the vocal folds, with the folds not meeting at the centre line" (Laver 1980:133).

In contrast, in the production of whispery voice a "moderate to high medial compression" is required. Comparing it with breathy voice, Laver says that whispery voice requires a "greater degree of laryngeal effort, (and) the friction component is more prominent than in breathy voice" (Laver 1980:134). He gives the laryngeal configuration for whispery voice as one in which there is a chink between the arytenoid cartilages. He goes on to suggest that it is possible to subdivide the friction component of whispery voice into a larger number of audible increments than the friction component of breathy voice. It would seem possible that whispery voice would set in first on the glottal continuum of Ladefoged (1971) with further relaxation of the glottis into a much wider glottal area resulting in breathy voice. Although Laver distinguishes between breathy voice and whispery voice, he admits that the distinction between the two categories is hard to make as there is a great deal of overlap. He therefore suggests that the two categories constitute points on an auditory continuum, rather than distinct qualities, and that setting a boundary between them is "merely an operational decision" (Laver 1980:133).

The picture that emerges from the discussion so far indicates that breathy voice is produced by more than one independent laryngeal settings:

1 Full glottal (i.e. glottis open along its length), or
2 Chink between the arytenoid cartilages.

For Ladefoged, these are two types of "breathy voice" (or "murmur"), while Catford draws a distinction between "breathy voice" and "whispery voice". Laver also distinguishes between "breathy voice" and "whispery voice" but considers that, auditorily, the two are points on a continuum.

The main physiological mechanism of the first type is a somewhat narrow opening of the glottis along its length and vocal folds do not close completely. The relatively open glottis serves as an opening for an escape of air throughout. This phenomenon is often described as one in which the vocal folds are "simply flapping in the airstream" (e.g. Ladefoged 1975:123, Catford 1977:99).

Considering now the configuration of the larynx in the second category, most of the writers have suggested a kind of triangular opening - described as "chink" - at the posterior part of the glottis (cf. Zemlin (1964) and Catford (1977:99)). Catford also distinguishes another type in which the chink is not fixed at the cartilagenous end.

#### 4.4.4.1 Linguistic Function of Breathy Voice.

Phonologically, breathy voice is contrastive in several languages. Contrast involving breathy versus regular voice is found in a number of languages, for example:

Nepali (Indo-Aryan)

| | | | |
|---|---|---|---|
| **pal** | 'rear' | **phal** | 'throw away' |
| **bal** | 'burn' | **bhal** | 'forehead' |

Marathi (Indo-Aryan)

| | | | |
|---|---|---|---|
| **ma:r** | 'beat' | **mha:r** | 'a castle' |

Newari (Sino-Tibetan)

| | | | |
|---|---|---|---|
| **ma:** | 'garland' | **mha:** | 'to be unwilling' |

Gujerati

| | | | |
|---|---|---|---|
| **tara** | 'stars' | **ta̤ra** | 'stars' |
| **bar** | 'twelve' | **ba̤r** | 'outside' |
| **pOr** | 'last year' | **pO̤r** | 'dawn' |

Hindi

| | | | |
|---|---|---|---|
| **bal** | 'hair' | **b̤hal** | 'forehead' |
| **d̪an** | 'charity' | **d̪han** | 'paddy' |

Tsonga (Bantu)

| | | | |
|---|---|---|---|
| **màkala** | 'embers' | **mhàka** | 'matter' |

Igbo (a Kwa language spoken in Nigeria)

| | | | |
|---|---|---|---|
| **iba** | 'to get rich' | **ib̤ha** | 'to peel' |
| **ida** | 'to cut' | **id̤ha** | 'to peel' |

Javanese

| | | | |
|---|---|---|---|
| **pipi** | 'cheek' | **bibi** | 'aunt' |
| **kali** | 'river' | **gali** | 'to dig' |
| **papa** | 'blunt' | **baba** | 'scene from a play' |

(The ‗ under consonant or vowel denotes breathy voice (murmur).
Sources: Ladefoged (1977:32-38 and 1983:352-3).

The words in the first column are distinguished from the ones in the second column because the former has voiced initial consonant (except the first example in Nepali) while the latter has breathy voice (murmur): indicates a long vowel. As already noted, Ladefoged considers that the production of breathy voice in Indian languages is different to production in Southern Bantu languages.

For more examples of languages that have contrast in phonation type involving breathy versus regular voice, see chapter 5 section 5.11.4.

Catford (1977:106) has also written on Javanese, where two types of voiceless stops, one written p, t, k etc. and one written b, d, g etc. are distinguished.

> "The observed differences are (1) that /b/, /d/, /g/ are pronounced with the larynx lowered, and this lowered larynx position persists into the following vowel, and (2) the vowel following /b/, /d/, /g/ is phonated with relaxed vocal folds, and some escape of air through a constant whisper-like chink-that is, the vowel following /b/, /d/, /g/ is "whispery voice", whereas the vowel following /p/, /t/, /k/ has much more tense phonation" (Catford 1977:203).

### 4.4.5 Summary.

In this chapter we have given a brief account of the structure of the larynx and the vocal folds. We have described the three cartilages that form the basic skeleton (of the larynx) within which the control of phonation is exercised and, the (intrinsic) muscles which effect the movement of the laryngeal cartilages and the larynx as a whole. There are five of these muscles (cf. section 4.3), and they generally perform three main functions: (1) open the glottis (PCA), (2) close the glottis (primarily INT and LCA) and (3) regulate the length of the vocal folds (primarily CT and VOC). A brief account of the vocal fold vibration during so-called modal voice was given.

We also surveyed the three main phonation types distinguished in the literature (modal, creaky and breathy voice) and provided an overview of previous descriptions given to them. Examples of languages which use these phonation types contrastively (particularly creaky and breathy voice) were given.

## 4.5 Notes.

1 "Glottalization" is another term often used by some writers with a similar meaning to creak or laryngealization. Some authors use it as a phonological concept, others as a phonetic concept, and it is not always clear which meaning is involved. Ladefoged expressed his doubt as to the appropriateness of using this term for phonetic purposes. He comments that glottalization "... might be appropriate as a phonological cover term for ejectives, implosives, laryngealized sounds and pulmonic articulation accompanied by glottal stops. But it is not very useful in precise phonetic descriptions" (Ladefoged 1971:28). It should be noted, however, that both terms suggest a constriction at the laryngeal level, a characteristic in keeping with the general characterizations of "creak" and "creaky voice" in the literature.

# Chapter Five

Review of Techniques for Voice Measurement.

## 5.1 Introduction.

In recent years one of the most important tasks in speech research has been the investigation of the laryngeal articulatory adjustments accompanying phonation. There has, of course, been a long tradition of investigation of vocal fold vibration for medical purposes and previous experimental studies that were directed toward the nature of the vocal fold's behaviour have largely been carried out by researchers in the field of speech disorders. See for example, Hirano (1976, 1979), Fourcin (1974a & b, 1981, & 1986).

Although a discussion of the medical literature would be quite useful, I shall make no attempt to review it here; the task is a large one and, in any case, this study is not oriented towards speech disorders. I am therefore going to limit myself to examples from linguistic studies.

A number of different techniques have been developed over the years, some of which have been used to investigate linguistically contrastive phonation types. An outline of some of these techniques, with some examples of their application in linguistic research is given below; I have chosen to discuss selected articles in some detail rather than give a complete review of the literature. Discussion of each technique is divided into the following sub-topics (however not all of the techniques contain all of the sub-topics).

1. Principles and Apparatus.
2. Advantages and Disadvantages of the Technique.
3. Comparison with other techniques,
4. Examples of works (linguistic and in a few cases, clinical) undertaken that will illustrate the use of the techniques and the kind of results that can be obtained.

List of Techniques:

| | |
|---|---|
| 5.2 | Laryngoscopy. |
| 5.3 | Stroboscopy. |
| 5.4 | Ultra High Speed Photography. |
| 5.5 | Fibreoptics. |
| 5.6 | X-ray. |
| 5.7 | Photo-electric Glottography. |
| 5.8 | Ultra Sound Glottography. |
| 5.9 | Electrolaryngography. |
| 5.10 | Electromyography. |
| 5.11 | Inverse Filtering. |
| 5.12 | Aerometry. |
| 5.13 | Acoustic Analysis. |

**5.2 Laryngoscopy.**

5.2.1 Principles and Apparatus.

Laryngoscopy is one of the techniques developed to study the functioning of the vocal folds. An observation can either be direct or indirect.

1 Direct Laryngoscopy.

Direct laryngoscopy is possible only when general anaesthesia is carried out or where an excised larynx is obtained by cutting through the throat of a dead person or animal. I do not intend to discuss this technique here and shall not provide a listing of investigations that have utilized the method.

2 Indirect Laryngoscopy.

This method provides a visual observation of the vibrating vocal folds in a mirror. It requires a local anaesthetic by spraying the pharyngeal and laryngeal areas. A laryngeal mirror (laryngoscope) is passed into the pharynx via the

Figure 5.2.1: Subject in position for laryngeal photography (A) and (B) experimenter prepared to photograph.

Source: Painter (1979:208).

mouth to obtain a clear view of the larynx. A light beam is directed onto the laryngeal mirror which provides illumination on the vocal folds and the image may be photographed from the mirror by a camera (cf. Fig. 5.2.1.).

The subject is asked to phonate a sound (usually a sustained vowel) at a certain pitch. The vocal fold vibratory behaviour is then studied as it is reflected in the mirror (cf. van den Berg 1968:284). Hard copies of the moving larynx and the position or movement of the vocal folds may be obtained for observation by filming or photographing the larynx while the subject is phonating.

### 5.2.2 Advantages and Disadvantages of the Technique.

Advantages:

The technique allows the investigator to view the vocal folds through the laryngeal mirror.

Disadvantages:

Van den Berg (1968:284) lists the following disadvantages of the technique:

1 Usually the speech sound under investigation is distorted due to the presence of the laryngoscope mirror in the mouth, and the protrusion of the tongue makes speech production difficult.

2 Not all speakers can stand the presence of the laryngoscope mirror inserted into the pharynx as this imposes severe limits on the movement of the supraglottal articulators.

3 Subjects with a very narrow throat may have difficulties in accommodating the mirror without obscuring the view of the larynx by the epiglottis.

4 The technique is not suitable for studying running speech because the mirror does not allow the subject to produce consonant sounds.

5 Viewing the vocal fold vibratory behaviour is not always satisfactorily achieved due to the fact that vocal fold vibration is extremely quick.

### 5.2.3 Some Applications of the Technique in Speech Research.

Esling (1978) provides a description of laryngeal configurations using laryngoscopic observation together with laryngographic records obtained separately (cf. section 5.9.4 for laryngographic results).

He based his investigation on his own production of several contrasting phonation types - modal voice, whisper, whispery voice, extremely whispery voice, breathy voice, harsh voice, ventricular voice, creaky voice and falsetto - associated with the different social classes of the Edinburgh community. He took modal voice as his point of departure and compared all the phonation types with it. He also compared the two records (laryngographic output and the laryngoscopic pictures of the laryngeal configuration) for each phonation type. The laryngoscopic pictures were obtained by filming the larynx using a high speed motion picture camera while still phonating the appropriate voice type. Finally, he discussed the relationship between the characteristic patterns of the laryngeal configuration and the social indicators which define different social groups of the Edinburgh speech community.

Esling's main observations were as follows:

In modal voice, the vocal folds come together and, under the direct light, appear to vibrate along their entire length. For breathy voice, the glottis is relatively wide open. As regards whisper, the arytenoids appear slightly more adducted than for breathy voice. The chink in the glottis is narrowed and the vocal folds and ventricular folds both appear slightly closer together. As regards whispery voice, he says,

> "the cuneiform tubercles of the arytenoids adduct slightly from their position for whisper, but do

> not approximate as closely as for modal voice. This leaves a slightly smaller chink in the glottis posteriorly than for whisper; while the anterior two-thirds of the vocal folds can be seen to vibrate" (Esling 1978:291).

As for extremely whispery voice, he says

> "the arytenoids are adducted at the corniculate tubercles, but appear slightly more abducted at the cuneiform tubercles than for whispery voice. The same chink appears at the posterior end of the glottis as in whispery voice, but the vibration of the vocal folds between this chink and the epiglottic tubercle appears under the direct light to be more extreme, with a greater excursion from mid-glottis, than in whispery voice" (Esling 1978:292).

For creaky voice, the entire glottal area is observed to constrict: arytenoids and epiglottic tubercle appear to be closed together and vocal fold vibration appears slower than in modal voice. And in falsetto,

> "the vocal folds stretch antero-posteriorly and only their thin edges approximate along their length and vibrate" (Esling 1978:296).

As regards harsh voice, Esling notes that

> "the vocal folds vibrate along their length as in modal voice, as far as they are visible" (Esling 1978:293).

And in ventricular voice he says,

> "the setting of the arytenoids and aryepiglottic folds resembles their setting in whispery voice ... however, the antero-posterior distance from the arytenoids to the epiglottic tubercle appears to be slightly reduced, and there is considerable activity, abduction and adduction including touching, of the ventricular folds" (Esling 1978:294).

## 5.3 Stroboscopy.

### 5.3.1 Principles and Apparatus.

The stroboscope is designed to have the following capabilities (cf. Hirano 1981:49 and van den Berg 1962, 1968:285):

1 To extract the fundamental period of the voice signal and obtain light flashes which correspond (at a repetition rate equal) to the vibratory pattern of the vocal folds;
2 to vary the phase point when the light flashes and
3 to indicate the fundamental frequency of phonation.

Basically, the apparatus available consists of a microphone, a light source, an electric control unit and a "propeller". The microphone is positioned at the speaker's larynx to pick up the fundamental frequency of the voice for synchronization with the stroboscope. The vocal folds (i.e. the successive vibratory cycles of the vocal folds) are stroboscopically investigated usually through a laryngoscope or a laryngeal mirror. Sometimes the vocal folds are observed using a fibrescope connected to a stroboscopic light which is used for illumination. The light source of the stroboscope emits intermittent flashes of light. The waveform of the subject's voice acts as a trigger signal for the light source.

A sharp, good image of the vocal fold posture at a particular point in the vibratory cycle results when the light flashes emitted are at the same frequency as that of the vocal folds vibration. When they do not synchronize, due to systematic phase delay of the consecutive light flashes, a slow motion effect is produced (cf. van den Berg 1968, Nielsen 1969 and Hirano 1981). Thus, unlike ultra high speed photography, which gives details of individual vibratory cycles, stroboscopy demonstrates a vibratory pattern over many successive cycles.

The stroboscopic technique (flashes of illumination at particular points in each cycle) can be used in conjunction with a number of techniques for observing the larynx. For example, Hollien et al. (1968) used a stroboscope plus X-ray, and Saito et al. (1975 and 1978) used a stroboscope with fibreoptics. Hollien et al. (1968) developed what they called a Stroboscopic Laminograph, which provides a permanent record of the vibrating vocal folds in a series of laminographic X-ray photographs (cf.section 5.6.4 for discussion of X-ray).

### 5.3.2. Advantages and Disadvantages of the Technique.

Advantages:

Stroboscopy allows the investigator to view the vibration of the subject's vocal folds in quasi-slow motion while the subject is phonating and without a high speed camera.

Disadvantages:

A major disadvantage of the stroboscopic technique lies in the very nature of the stroboscopic principle. A stroboscopic picture is but a multiple image from various additional cycles of vibration. It does not present a true picture of the activities within each individual vibratory cycle. The effect is one of blurring of the rapidly vibrating fold edges, which may be affected by such changing factors as amplitude of motions or duration of closed and open phase.

### 5.3.3. Comparisons With Other Techniques.

Examples of comparisons between stroboscopic observation and laryngography are discussed in section 5.9.3.

## 5.4 Ultra High Speed Photography (UHSP).

### 5.4.1 Principles and Apparatus.

Ultra high speed photography provides a permanent record of laryngoscopic observation by photographing the vibrating vocal folds at ultra high speed. The technique was developed by scientists at the Bell Telephone Laboratories in the late 1930s (cf. Bell Telephone Laboratories 1937). Since then improvements have been made by several investigators in both the lighting source and the observation procedure. (cf. Moore, et al. (1962), Soron (1967), Gould (1977), Yoshida (1969), Yoshida et al (1972) and Tanabe et al (1975)). Hirano (1981) also provides a good summary of the literature.

Gould (1977) used a different lighting system to photograph the vocal folds. He used a high-intensity, high-speed stroboscopic light, filmed the glottis with an optical laryngoscope and displayed the image on a display scope.

Describing the technique, he says:

> "We have developed a new lighting system for this type of photography employing a high-intensity, high-speed stroboscopic light developed for us by E. G. and G., Inc. of Boston ... the tube flash rate is triggered and synchronized by the camera shutter, resulting in one flash per frame using a Hycam model K201 as the high-speed camera. With this method we were able to reduce the exposure time to less than 2.1 microseconds per frame. This has resulted in increased sharpness of the image of the vocal fold edge in individual frames. This, in turn, allows for a more accurate measurement of vocal fold dimension" (Gould 1977:139).

The apparatus for U.H.S.P., basically consists of an extremely bright light source; an optical system (usually a laryngeal mirror) to reflect light from the subject's larynx to a camera unit; an ultra high speed camera; an electronic system to operate the light source and the camera; and a pulse generator which provides time marks. See Fig. 5.4.1 for an illustration of the photographing equipment.

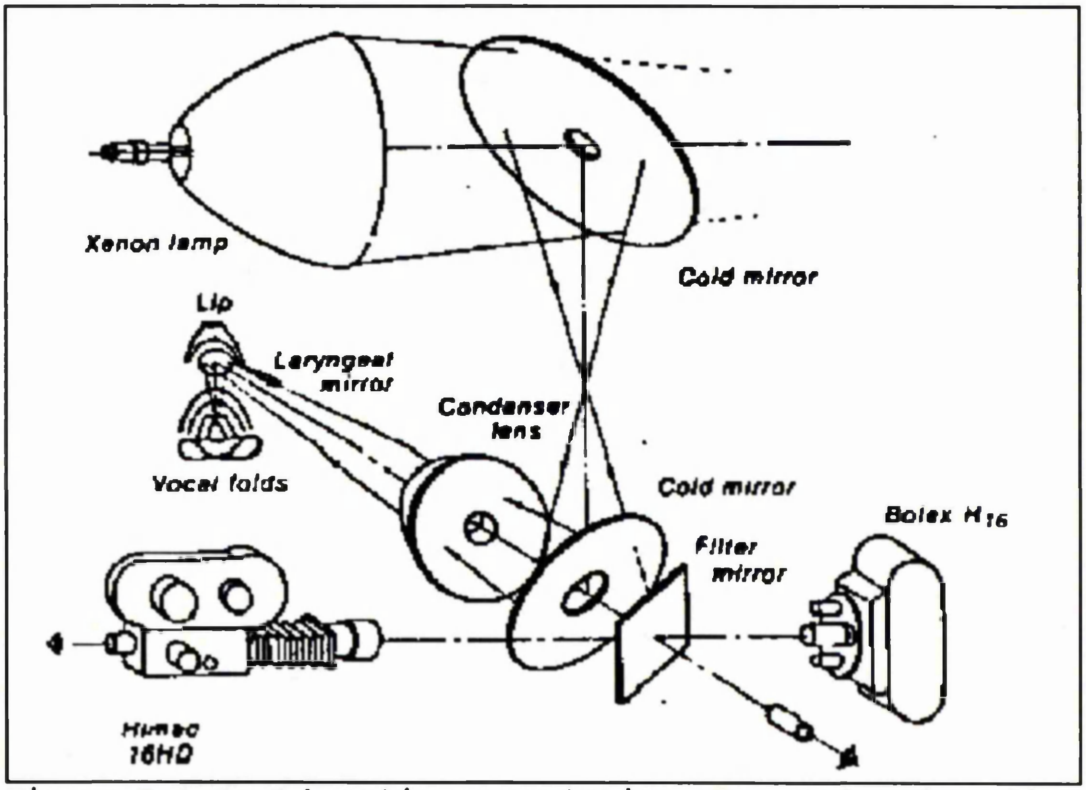



Figure 5.4.1: Schematic presentation of a system for ultra high speed photography of the vocal folds.
Source: Hirano (1981:55).

With this apparatus the vibrating vocal folds, as seen in the laryngeal mirror, are photographed using the high speed camera at a rate which is about 20 to 30 times the fundamental frequency of phonation. A frame-by-frame analysis of various parameters may then be carried out in order to determine vibratory behaviour of the vocal folds.

5.4.2 Advantages and Disadvantages of the Technique

Advantages:

The technique provides fine details of the vibrational patterns (especially during transitions) of the glottal cycles. In other words, it presents a (near) true picture of the activities within each vibratory cycle when a frame-by- frame analysis of the film is made in slow motion. Thus, UHS pictures provide one of the best ways to study the complex vibratory movements of the vocal folds at different frequencies and intensities (cf. Moore et al. 1962:167 and van den Berg 1968).

Disadvantages:

Hirano (1981:55) lists some of the following draw-backs in using the technique.

1 UHSP requires expensive apparatus.
2 Data analysis is a very time-consuming exercise, as several thousands of frames must be analyzed.
3 The use of a laryngoscopic mirror in the vocal tract does not usually provide a complete view of the whole vocal fold, and may cause great discomfort to the subject.
4 Untrained subjects, who in addition may present a pharynx or larynx with narrow anatomy, are very difficult to photograph.

5.4.3 Comparisons With Other Techniques.

In 1959, Miller studied the properties of the vocal mechanism with reference to the shape of the vocal fold wave. The shape of this wave was determined by two independent methods; (1) by inverse filtering (cf. section 5.11.3) and (2) by measuring the area of the vocal fold opening as a function of time through the use of a motion picture studies.

A comparison of the results obtained using the two methods revealed a lot of similarities (cf. Fig. 5.11.2 & 5.11.3).

Sonesson (1960) correlated the photo-electric glottographic waveform of the vibrating vocal folds with HSM pictures (cf. section 5.7.3). The purpose of the experiment was to compare the magnitude of the open quotient obtained by the two methods (cf. section 5.7.3 for a definition of 'open quotient'). A high speed camera was used, operating at a rate of 3000 frames per second. The subject's vocal fold were filmed while phonating the vowel /ä/ [ę] with high intensity at a given frequency (value not given). Three subjects were recorded. In each film 10 vibratory cycles were analyzed for determining the open quotient (cf. section 5.7.3). In each picture the distance between the medial margins of the two vocal folds was measured, approximately equidistant from the anterior and posterior commissures of the glottis. Comparison between the open quotients from glottograms and high speed motion pictures shows that the open quotient is of the same magnitude in the glottograms and in the high speed motion pictures (cf. Table 5.7.1).

Another study which involved comparison of high speed photography with another technique was that of Soron (1967). He correlated the film of the vibrating vocal folds with photo-electric glottogram (showing the movement of the vocal folds) and an acoustic output, so as to compare the magnitude of the open quotient obtained from these methods (he did not give any illustrations). Synchronization of the acoustic waveform was obtained by recording the sound waveform directly on the film. The subject's vocal folds were filmed while phonating a sustained vowel /a/=[E] with high intensity at a given frequency (value not given).

In each picture the distance between the medial margins of the two vocal folds was measured approximately equidistant from the anterior and posterior commissures of the glottis. On comparison of the open quotient obtained from the glottograms, the acoustic output and that of the HSM pictures, Soron noted that:

1 The open quotient is of the same magnitude in the glottograms and in the high speed motion pictures.
2 The phase difference between the upper and the lower edges of the vocal folds observed by other investigators was found in this study also.

In another study that sought to determine the suitability of photo-electric glottography as a technique for monitoring laryngeal actions, Coleman and Wendahl (1968) made a comparison between the technique with high speed motion photography (cf. section 5.7.3). The subject's larynx was photographed on a 16-mm film at a speed of approximately 5000 frames per second. The glottal area function was determined by traditional polar planimeter methods and the total area was plotted as a function of time. For how the photo-electric glottograms were measured see section 5.7.3. The amplitude and area curves thus derived from the two methods were plotted as function of time (cf. Figs. 5.7.3 to Fig. 5.7.4).

Ultra high speed motion photography has also been used in conjunction with ultra sound glottography in an investigation which sought to determined the reliability of ultra sound glottography in monitoring the vocal folds during phonation by Beach and Kelsey (1969, cf. section 5.8.3).

Childers et al. (1984) used the technique in collaboration with electroglottography in the assessment of the larynx motion (cf. section 5.9.3). In the study, the authors filmed the vibratory pattern of the vocal folds while simultaneously recording the electroglottographic and acoustic signals. The electroglottographic and acoustic signals were also filmed off an oscilloscope and appeared along the edge of the high speed laryngeal films. A comparison of the waveforms obtained by the techniques showed great similarity in the periodicity of the electroglottographic waveform and the glottal contact area waveform derived from the high speed motion films.

### 5.4.4 Some Applications of the Technique in Speech Research.

Smith (1954) examined the vibratory patterns of the vocal folds by photographing them. The subject was a 39 year old man phonating a sustained vowel at a pitch of about 150 cps. Thirteen original pictures were selected from a number of others to illustrate the phases of one complete cycle of vibration of the vocal folds (glottal opening and closing movement.

An examination of each picture of the film reveals that narrowing of the glottal area is the first event in movement. In other words, phonation begins by a sucking movement. At a normal pitch (speaking range) the sucking event is particularly prominent. At low pitch the relative closure time is found not to be very long.

These observations led Smith to suggest that adduction is brought about by a sucking effect, an assumption which he claims agrees with earlier findings from Bell Telephone Laboratories' films (cf. Bell Telephone Laboratories 1937).

Using UHS photography, Timcke, von Leden and Moore (1958) explored the details of laryngeal vibration during the opening and closing phases (vocal fold abduction and adduction) of the vibratory cycle of the normal human vocal folds. For the purpose of the study, the authors made UHS motion pictures of the vocal folds of two of them (P. Moore and H. von Leden). A number of other subjects (male and female) with normal vocal folds were also photographed with an UHS camera while phonating a modal voice vowel on high, medium and low pitches (the values were not given). In addition, artificial larynges were constructed in the laboratory, and subjected to the same thorough investigation.

The pictures of the vocal folds which were selected for measurements were subjected to frame-by-frame analysis. In order to relate the lateral excursion of the vocal folds to the total vibratory cycle each picture was projected separately in sequence until the entire cycle had been measured. The centre of the glottis was located by dividing the antero-posterior diameter in the midline. All measurements were taken through this plane from the margin of one vocal fold to the margin of the other fold, and the resulting figure was then divided by two. The term "lateral excursion" of the vocal fold refers to the distance from the midline of the glottis to that portion of the vocal fold which in the two-dimensional photograph appears as the medial edge; in the beginning of the opening phase this medial edge is taken to be the upper lip of the vocal fold margin, and during the closing phase the lower lip.

For comparison between the opening and closing phases under different conditions and in the different subjects the results were plotted (cf. Fig. 5.4.2 which shows an illustration of a single cycle). On each graph the vertical axis represents one-half of the glottal width. On the basis of their observations the authors report the following conclusions:

1 That the process of abduction (opening phase) differs from that of adduction (closing phase). For instance,

they note that the vocal folds open much faster than they close. In most cases the speed tends to increase gradually during the early part of the opening phase. After that, the speed remains almost constant until the closure has almost reached the maximal upper lip of the vocal fold margin. See also Fig. 5.4.3: low intensity and low pitch, Fig. 5.4.4: medium intensity and medium pitch, and Fig. 5.4.5: high intensity and high pitch.

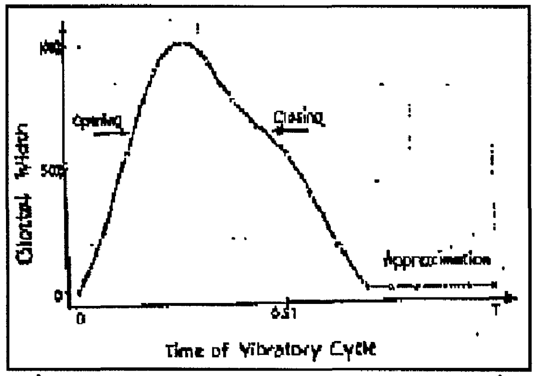


Figure 5.4.2: Graphic illustration of a single cycle of vibration.

2 Speed quotient (the ratio of the opening to the closing phases, calculated as the average speed of closing divided by the average speed of opening) varies directly with the intensity of the sound produced, and it is not influenced by either sex or changes in phonation type. So, at low intensities, the speed quotient remains always low, and increases at high intensities.

3 The open quotient (the proportion of the cycle in which the glottis is open, calculated as the percentage of the cycle during which the glottis is open divided by the duration of the entire cycle) is inversely proportional to the intensity of the sound produced; it varies but slightly with changes in pitch. In other words, the open quotient decreases with increasing intensity.

4 The amplitude of the laryngeal vibrations as measured increases considerably with increasing intensity.

Figs. 5.4.3. to Fig. 5.4.5 are representative graphs showing vocal fold vibration at different pitches and intensities (see above) during modal phonation. The rising section of the curve shows the opening phase and the declining section the closing phase. The horizontal section is the period of maximum approximation. Source: Timcke et al. (1958:4-5).

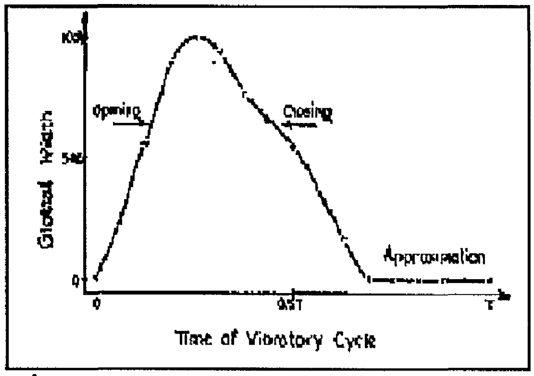


Figure 5.4.3:

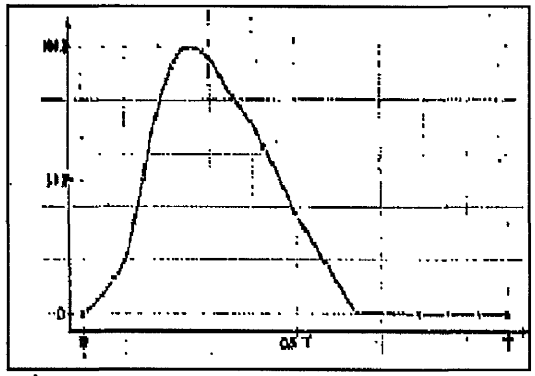


Figure 5.4.4:

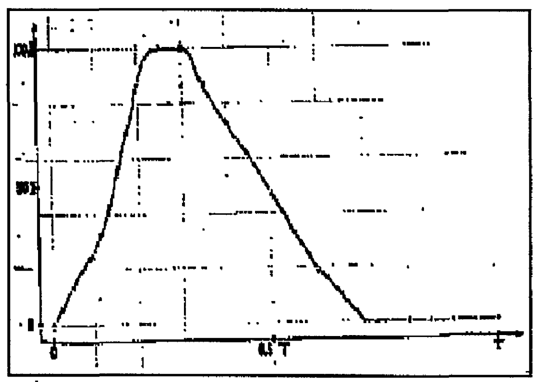


Figure 5.4.5:

Tanabe et al. (1975) also presented a measurement of the vocal fold size and motion using a specially designed technique for filming the glottis. They used a data reduction system which included an analysis projector capable of projecting film frame-by-frame in conjunction with a PDP-12 computer for recording and processing the visual data. Several points were marked on the vocal fold images, dividing them into equal parts along their length (cf. Fig. 5.4.6).

Three subjects were recorded phonating a sustained vowel at different frequencies and intensities (frequency values not given). The analysis program was then used to compute the following parameters as a function of time from the various points on the vocal fold images. They were:

1 Excursion curves of both the right and left vocal folds at all measured points.
2 Glottal width, length, and area.

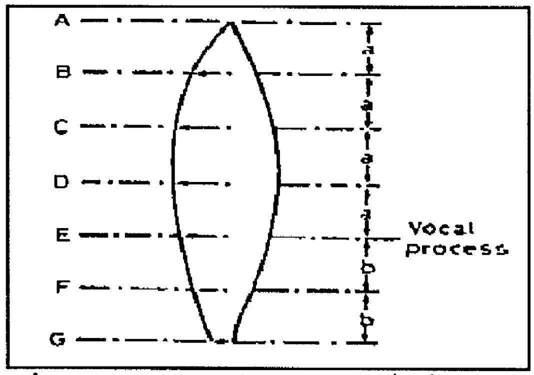


Fig. 5.4.6. Shows position of points marked on the vocal fold images.
Source: Tanabe et al. (1975:80).

The results were plotted graphically (cf. Fig. 5.4.7(a-i).

Fig. 5.4.7(a-i) Glottal area and excursion of each measured point. The letters A-G represent the glottal width at the measured points and the curve designated area represents the glottal area as a function of time during one vibratory cycle.
Source: Tanabe et al. (1975:82-83).

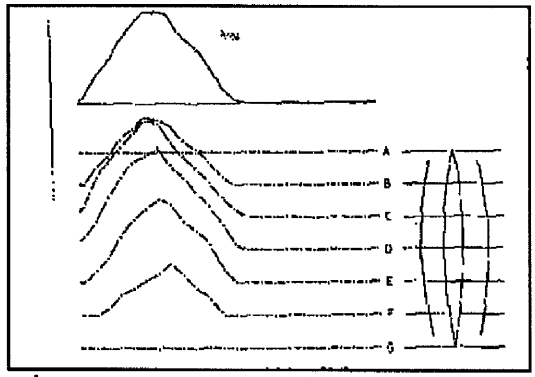



Figure 5.4.7: (a)

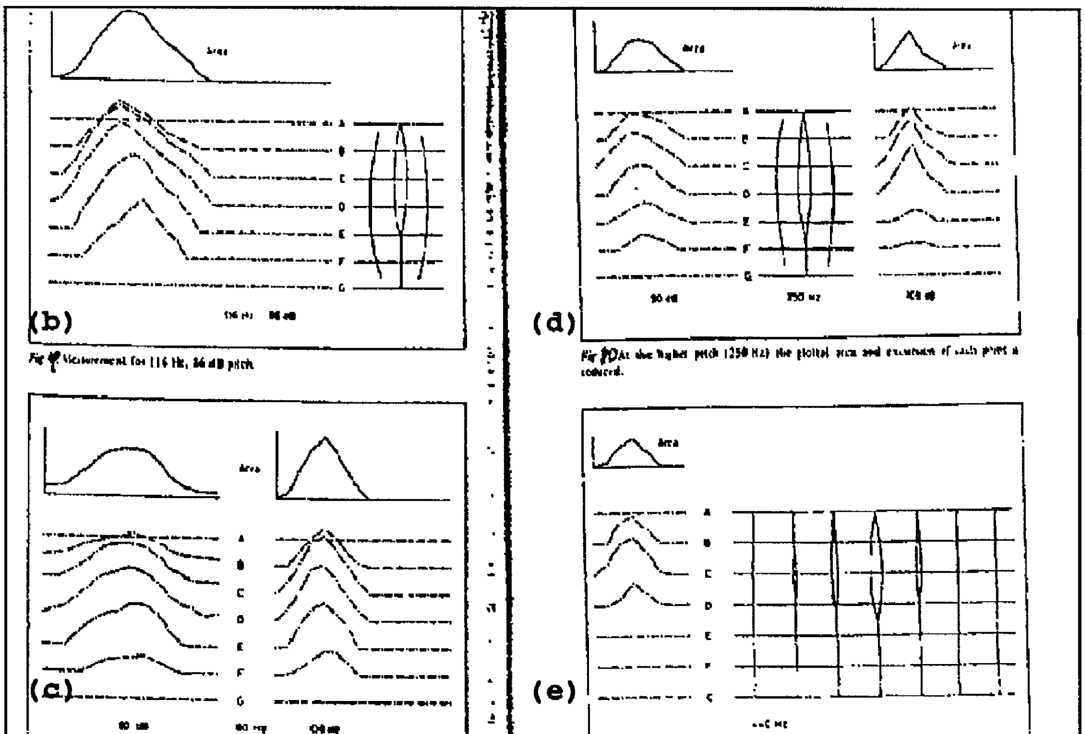



Figure 5.4.7

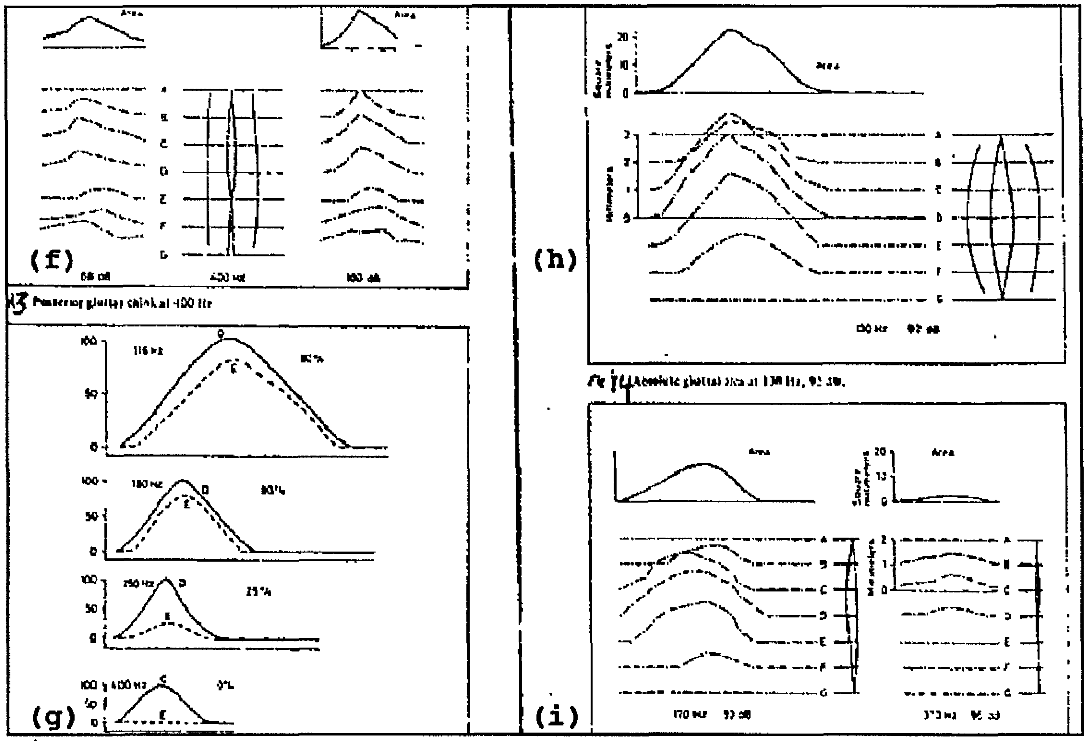


Figure 5.4.7

Tanabe et al. noted that at the various discrete points on the vocal fold there are different types of motion during the phonatory cycle. For example, (h) shows the relationship between the maximum vocal fold excursion and the excursion of the vocal process. Dark lines on the graph represent the glottal width at the point of maximum amplitude; broken lines represent the glottal width at the vocal process as a percentage of the maximum width of the glottis. The results show that there is a relative decrease in maximum glottal width as fundamental frequency rises. At 400Hz no vibrations are observed at the vocal process.

## 5.5 Fibreoptics

### 5.5.1 Principles and Apparatus.

Sawashima and Hirose (1968) first described this technique for observing the larynx, using a flexible fibreoptic laryngoscope to provide a light source and a photo sensor as a detector. It allows a direct visual observation of laryngeal action during speech production with minimal obstruction to the articulatory movements of the speech organs.

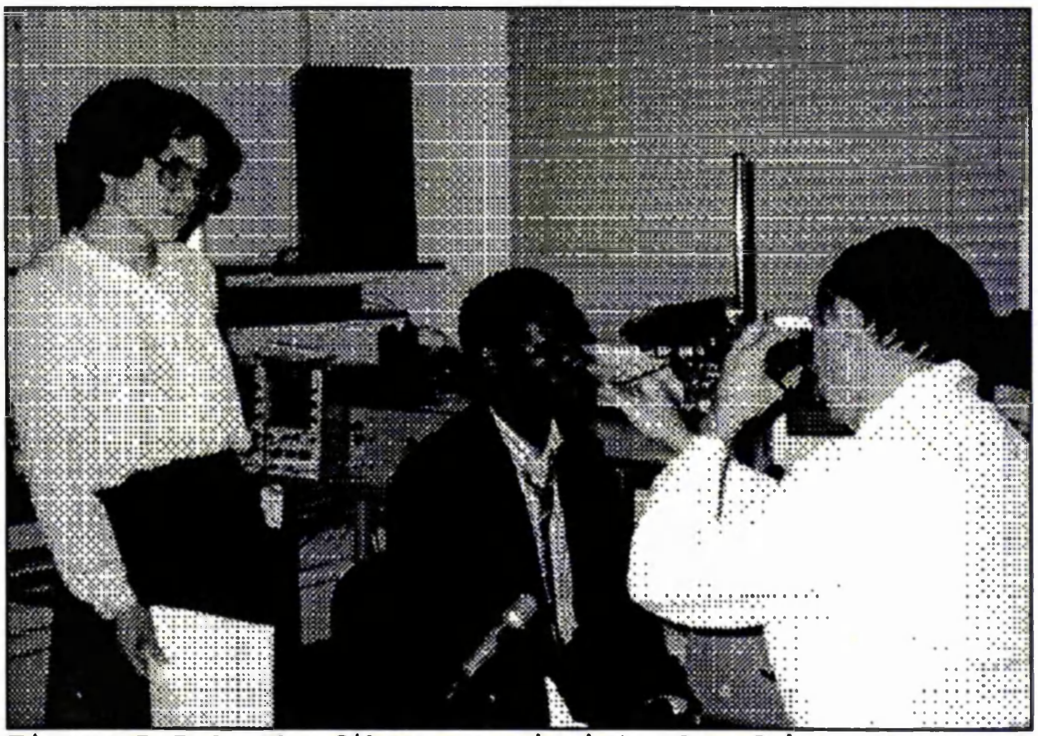


Figure 5.5.1. The fiberscope is introduced into the nasal cavity.

During examination the subject is seated in a chair with the head tilted backwards. The observer carries out a surface anaesthesia of the mucous membrane of the nose and pharyngeal wall. He then inserts the flexible fibreoptic laryngoscope into the nasal tract. See Fig. 5.5.1 which shows the method of introducing the fibrescope into the nasal cavity.

The thin flexible fibrescope plastic tube consists of two fibreoptic bundles: one is the image guide and the other is a light guide for illumination. The image guide consists of a number of very thin fibres, each of which represents a picture element in the image (cf. Fig. 5.5.2).

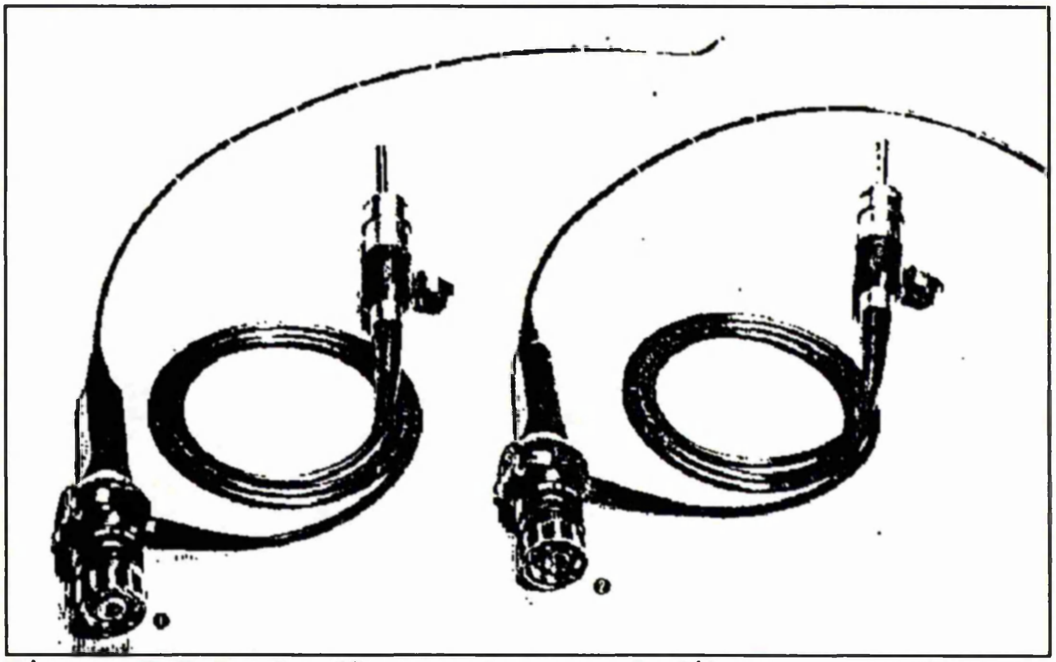


Figure 5.5.2. An Olympus laryngeal fiberscope. NPF type (1) and VF type 4A2.
Source: Painter (1979:208).

The movements of the vocal folds may be recorded on film or video tape (the filming system sometimes employs stroboscopy or high speed photography, cf. sections 5.3 and 5.4). They may then be examined frame-by-frame in order to obtain the time course of (visible) vocal fold activity. A simultaneous recording of the speech signal may also be made onto audio tape. In this way it is possible to easily and accurately achieve synchronization between a particular part of the film and the trace of an acoustic event (cf. Sawashima 1977).

### 5.5.2 Advantages and Disadvantages of the Technique.

Advantages:

1 The technique provides instant pictures of adjustment of the larynx and other articulatory organs during speech;

2 Direct visual observation of laryngeal activity during speech production is possible with minimal obstruction to the articulatory movements of the speech organs.

Disadvantages:

This technique too is not without some shortcomings. Sawashima (1977:44) lists some of the disadvantages of the method as:

1 Changes in the position of the tip of the scope relative to the larynx, which occur with some articulatory movements, may cause variations in the image size and the viewing angle of the larynx;

2 Backward tilting of the epiglottis also interferes with the view of the folds. This may make it difficult to obtain a good view for nasal and back vowels;

3 The small diameter of the light guide may limit the amount of illumination and consequently the vocal folds may not be illuminated enough for observation of individual vibratory cycles.

### 5.5.3 Some Applications of the Technique in Speech Research.

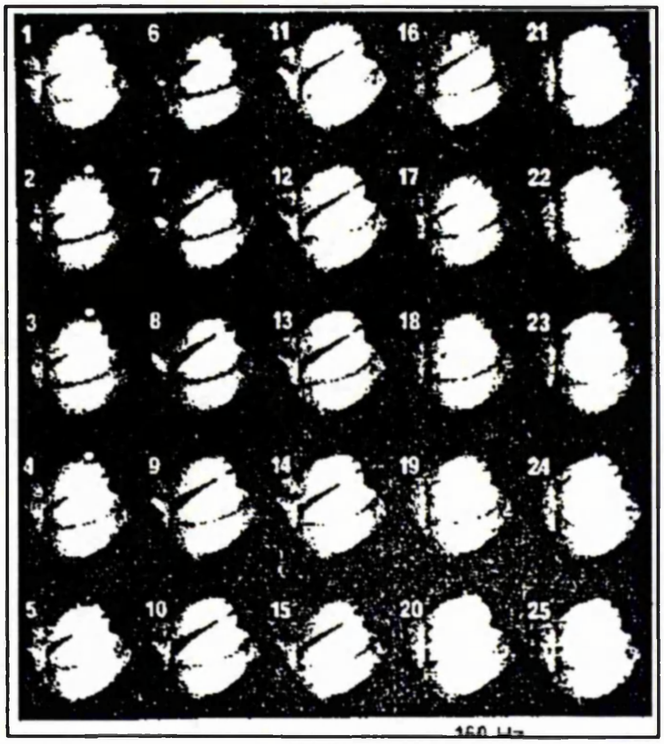



Figure 5.5.3: Normal vibratory patterns of the vocal folds in a 51 year-old male, rephotographed from 16mm cinematography. The anterior commissure is seen in the lower and left parts of the picture. Phases: 1-9: Opening; 10-18: Closing; 19-25: Closed phase. Source: Saito et al (1978:243).

Since Fibreoptics was invented as a scientific tool, it has been used in a number of language studies. Saito et al. (1978) observed stroboscopically the vibratory pattern of the vocal folds through a flexible fibreoptic laryngoscope. The subject was a 51 year old man whose vocal fold vibratory patterns were photographed. See Fig. 5.5.3. for a series of photographs of a normal vibratory pattern of the vocal folds.

The authors found that the stroboscopic vibratory pattern of the vocal folds could be obtained naturally, hence the usefulness of the technique in the study of functioning of the vocal folds.

Kagaya (1971) reports a study he made of Korean stops. There are three types of stops in Korean. They are "unaspirated" (Type 1), "less aspirated" (Type 2) and "aspirated" (Type 3). In the literature the stop types have been called by various different terms. The "less aspirated" and the "unaspirated" have been called "weak stop" and "strong stop" respectively, "lenis" and "fortis", or "lax" and "tense", by different investigators. These terms, however, have been used in many different ways. In order to avoid any possibilities of misinterpretation, I have decided to use the terms "aspirated", "weak" and "strong" (cf. Han et al 1970:112).

Kagaya filmed the vocal folds of one male native speaker of Korean during the production of the three stops using the fibrescope and obtained measurements of glottal width. The images obtained through the fibrescope were recorded in the form of a 16-mm black and white film, and the speech signal was recorded simultaneously on magnetic tape. For representing the glottal width, the distance between the vocal processes was measured, frame by frame, from the glottal images of each representative utterance of each syllable. In Fig. 5.5.4 the measured distance thus obtained is plotted against the frame number. Kagaya found that the photographs obtained reveal very different laryngeal adjustments for the triplet homorganic stops.

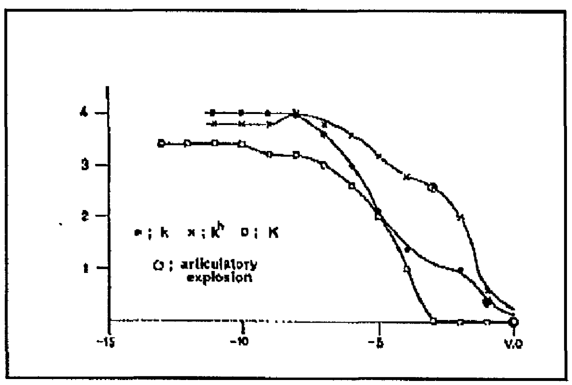



Figure 5.5.4: Time courses of the glottal width for representative utterance samples of the three types of velar stops. The open rectangles represent the strong stop, the crosses the aspirated and the filled circles the weak stop. The abscissa represents the frame number counted back from the time of voice onset (VO), one frame corresponding to 1/24 sec. The ordinate gives an arbitrary scale for the glottal width.
Source: Kagaya (1971:16).

He reported the following findings. Maximum glottal opening during occlusion was:

1 Largest for the aspirated stop. The glottis only closes rapidly after articulatory release; at the vocal processes the folds remain slightly separated (cf. Fig. 5.5.4);
2 Intermediate for the weak stop (the glottis begins to close gradually and the vibration of the membranous portions starts while the glottis at the vocal process is still open (cf. Fig. 5.5.4));
3 Lowest for the strong stop. The glottis begins to close rapidly starting from the rest position and complete contact of the vocal processes is found before voice onset.

There is also great variation between the three stops in timing of the closing gesture relative to the articulatory release (cf. Fig. 5.5.4).

1 Release generally occurred near the moment of maximal glottal opening for the aspirated stop;
2 For the weak stop, it was observed that even though the glottis remained open at release, there was a more or less continuous decline in glottal area throughout the occlusion;
3 During the strong stop closure period, the vocal folds were found to be closed tightly together prior to release.

Hirose, Lee and Ushijima (1974) made a fibreoptic study in conjunction with an electromyographic investigation (cf. 5.10.3) of the actions of the laryngeal muscles during the production of Korean stops. In the fibreoptic investigation, motion pictures of the glottis were taken using a fibrescope at a film speed of 60 frames per second. The subject (who was one of the experimenters) was an adult male native speaker of Korean from the Hwa-dong-myun dialect area. The subject read randomized lists (total not given) of isolated /CVCV/ and /VCV/ (where /V/ was always /i/) sequences, which did not violate any phonological constraints of the dialect under investigation). The list of words was not the same as for the EMG part of the study.

The parameter examined was glottal width. Approximate frame sequences for each type of stop were then examined frame-by-frame with special reference to the time course of glottal width as measured at the vocal processes.

The results were similar to those of Kagaya (1971). The authors report the following findings:

1 Considerable differences in glottal width occur during the consonantal closure period between the three stop types (cf. Fig. 5.5.5);
2 A comparison of strong and weak stops versus aspirated stops shows that during articulation of the strong and weak stops the glottis begins to close earlier relative to the stop release, while it stays wide open until the release in the aspirated stop;
3 A comparison between strong and weak stops shows that in strong stop the glottis closes somewhat more rapidly and a complete contact of the vocal process is found before the stop release, while in weak stop the glottis closes gradually.

Sawashima et al. (1980) investigated the syllable final stops in Korean. As noted above, Korean has three types of stop which contrast in syllable-initial position. In syllable-final position only single type occurs, produced without oral release. Sawashima calls them "applosives".

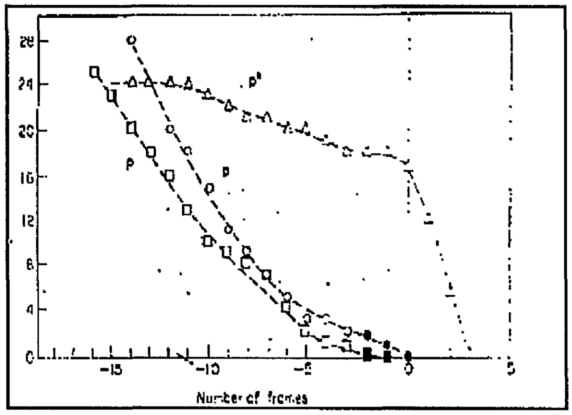



Figure 5.5.5. Time courses of the glottal width for representative utterances samples of the three bilabial stops in absolute word-initial position. The rectangles represent strong stop, the circles weak stop and the triangles, the aspirated stop. Filled rectangles and circles indicate that the vocal fold vibration was observed in that frame. The zero on the abscissa marks the release of stop closure.
Source: Hirose, Lee and Ushijima (1974:150).

The study investigated the laryngeal adjustments for the syllable-final stops in various phonological conditions, such as end of sentence, before syllable-initial velar stops and before syllable-initial fricatives. Three female and two male adults acted as subjects. All subjects were native speakers of the Seoul dialect and fluent speakers of Japanese. The subjects read the test words in a sentence. All test words are meaningful Korean words containing syllable-final stops. Using the fibrescope the vocal folds of the subjects were photographed at a rate of 50 frames per second. The distance between the tips of the vocal processes of the arytenoid cartilages was measured when the glottis was open. An enlarged image of the films for each consonantal sound was examined frame-by-frame.

Sawashima et al. compared the length of glottal opening of each stop with another member of the set (cf. Figs. 5.5.6 and 5.5.7). They note that:

1 For syllable-final stops at the end of a sentence, the glottis begins to open one or two frames after oral closure, the extent of the opening remaining small for a time period of 4 to 5 frames after closure (cf. Fig. 5.5.6);

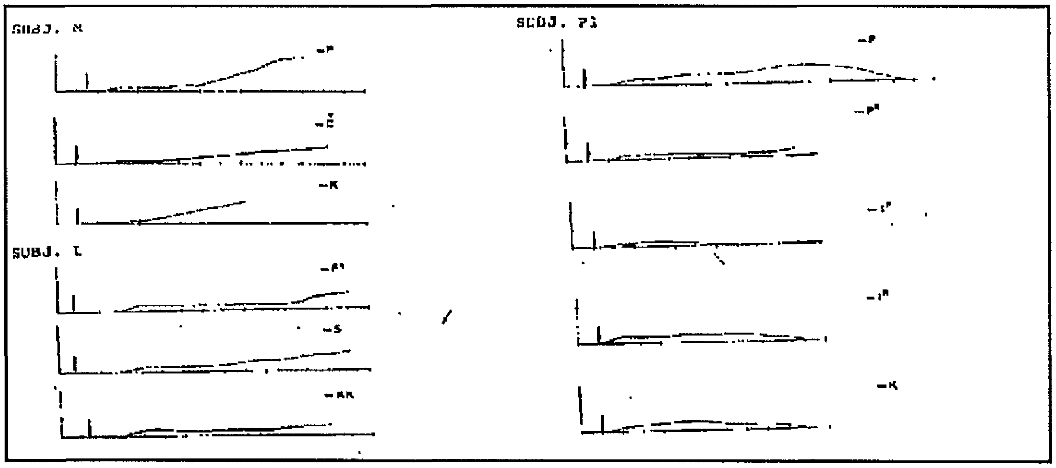


Figure 5.5.6: Typical examples of the glottal time curves for the syllable-final applosives at the end of sentence for three subjects. In each graph the abscissa is the time axis demarcated by the interval of each film frame (20 sec), and the ordinate corresponds to the apparent glottal width measured on an arbitrary scale. The downward arrow indicates the time point of the articulatory closure. The glottis begins to open at, or one or two frames after, the oral closure for all the test words, the extent of opening remaining small for a time period of 4 to 5 frames after closure.
Source: Sawashima et al. (1980:131).

2 Syllable-final stops followed by syllable-initial velar stops show a small degree of glottal opening during oral closure, the glottis being completely closed or nearly closed at oral release (cf. Fig. 5.5.7).

3 As regards syllable-final stops followed by syllable-initial fricatives, a fairly large glottal opening was observed for both the weak and strong fricatives, although the degree of glottal opening tended to be larger for the weak sound when compared to the strong one (cf. Fig. 5.5.8).

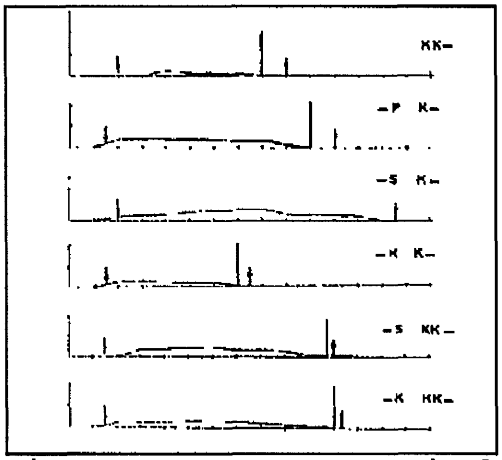


Figure 5.5.7. Typical examples of glottal time curves for the sequences of the syllable-final applosives followed by weak and strong velar stops for speaker M.
Source: Sawashima et al (1980:132).

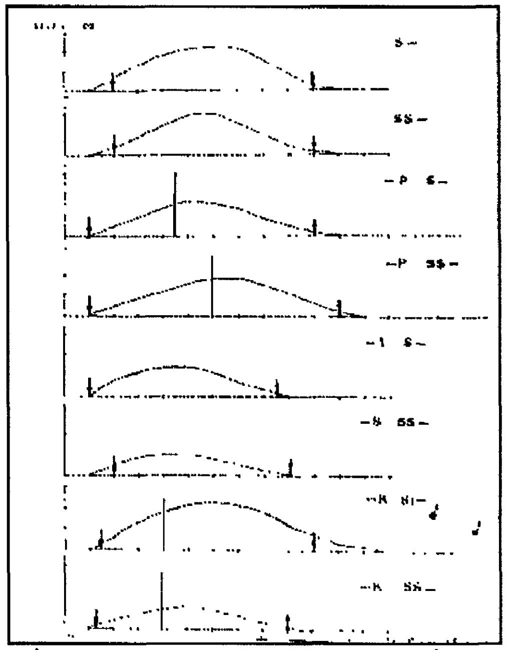


Figure 5.5.8. Typical examples of the glottal curves for the sequence of the syllable-final applosives followed by the fricatives for speaker M.
Source: Sawashima et al. (1988:133)

From these results Sawashima et al. concluded that the basic laryngeal feature of the Korean syllable-final applosives is characterized by a small degree of glottal opening which begins at or slightly after the oral closure. In the case of the final applosives followed by the initial stops and fricatives, the laryngeal configuration of the final applosives appears to be assimilated to that of the following consonant, irrespective of the difference in the place of articulation, as far as the glottal abduction/adduction is concerned.

Kagaya and Hirose (1975) presented a study which attempts to specify the properties of Hindi homorganic stops by combining fibreoptic analysis with acoustic analysis (cf. section 5.13.4) and electromyographic analysis (cf. section 5.10.3). Hindi stop consonants are classified into four types for each place of articulation. These four stop types are usually referred to as voiced unaspirated e.g. /b/ voiceless unaspirated e.g. /p/, voiced aspirated e.g. /bh/ and voiceless aspirated e.g. /ph/ (cf. Kagaya and Hirose 1975:27).

In the experiment a 44 year old male native speaker of Hindi served as subject. He read a list of trisyllabic nonsense phrases containing bilabial and dental stops belonging to the four types syllable-initial in the final syllable. The words were read in isolation and the whole series repeated three times. In addition the subject also read disyllabic nonsense phrases embedded in a meaningful sentence. The consonants of the disyllabic words were as above. The series was repeated three times; thus, 12 samples were obtained for each stop type for both bilabial and dental places. (For more details concerning the word list see 5.10.3).

Films of the glottis were taken during the production of these consonants at word initial and medial positions by means of a fibrescope, and the distance between the vocal processes was measured.

The results showed that the time course of the glottal width is different for each of the four types of stop consonant. See Fig. 5.5.9 which presents typical contours of glottal width for each stop type for the bilabial stops.

A summary of their results is as follows:

1 A large glottal opening was observed for voiceless aspirated stops /ph/ and /th/. The articulatory release takes place just before the point when the maximum glottal opening is reached. The authors note that this facilitates voicelessness and gives rise to a considerable period of aspiration. Compare the results reported for Korean aspirated stops above;

2 For voiceless unaspirated stops /p/ and /t/, the glottis is nearly closed to the phonatory position at the articulatory release, although a small amount of glottal opening is observable during oral closure;

3 For voiced aspirated stops /bh/ and /dh/, the glottis is mostly closed during oral closure until it begins to open just before oral release. Maximum opening is reached only after release. There is vocal fold vibration during the closure period;

4 The voiced unaspirated stops /b/ and /d/ are characterized by a closed glottis all through the articulatory closure period and by a relatively short closure period.

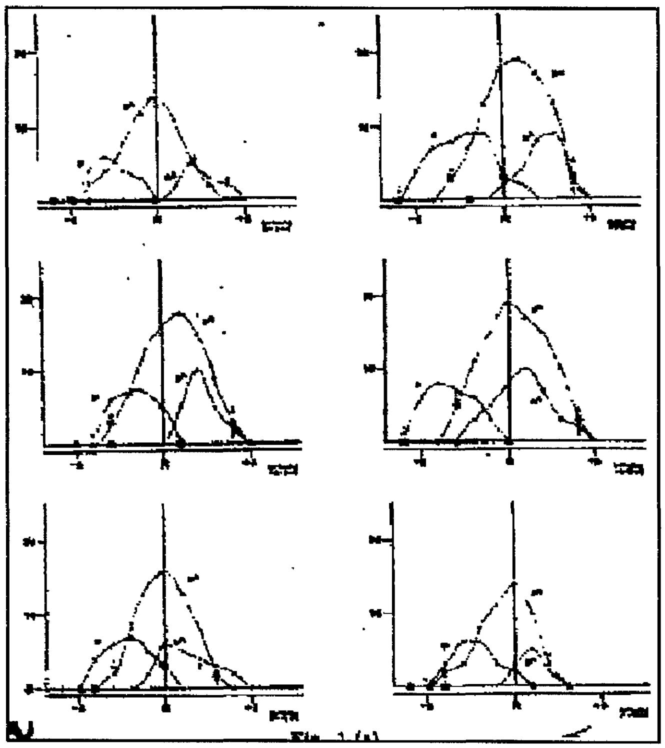


Figure 5.5.9. Typical contours of glottal width for the bilabial stops. The open triangles represent the voiceless aspirated stop, the filled triangles the voiced aspirated type, the open circles the voiceless unaspirated type and the filled circles the voiced unaspirated stop. The abscissa represents the frame number counted back from the time of articulatory release, one frame corresponding to 20 msec, and the ordinate the apparent glottal width in an arbitrary scale. Also "O" means the voice onset, the square box the articulatory implosion and the arrow the frication offset and the dotted arrow, the voice offset of the preceding vowel. Source: Kagaya and Hirose (1975:30-31).

Sawashima et al. (1976) used the fibreoptic technique to determine the nature of the glottal opening and closing gestures during articulations of single and geminate voiceless consonants in Japanese. Four male adult Japanese of the Tokyo dialect served as subjects. They read twenty-four meaningful Japanese words in a frame sentence. The single voiceless stops /p/, /t/ and /k/ and the fricative /s/ and the affricate /ts/ were produced in word initial and word medial positions, while the geminates were produced only word medially (geminate stops occur only in word medial position in Japanese). The number of utterance samples obtained for each of the test words ranged from four to six. The glottis was filmed using a 16-mm cine camera at a rate of 50 frames per second. Simultaneously with the filming, speech signals and synchronization time marks were recorded. Approximate frame sequences for the consonants were examined in a frame-by-frame analysis using magnified film images. In this way, the time course of glottal aperture width was determined, as measured at the vocal process (cf. Fig. 5.5.10).

The variables measured were:

1 Closure duration (determined from spectrograms) and
2 Glottal width measured between the tips of the vocal processes of the arytenoid cartilages.

Comparing the values for the different items Sawashima et al. found that:

1 In general, there is a fairly large opening of the glottis for /s/ in both word initial and medial positions, and for the voiceless stops, glottal opening is greater in word initial position than in word medial position (cf. 5.5.10, see also Fig. 5.5.12 which shows the averaged time course of the glottal opening and closing process for three subjects);
2 For geminate stops, the results showed that although consonant closure duration is consistently longer than for the corresponding non-geminate stops, the degree

of glottal opening is often observed to be as small as for word-medial non-geminates. The findings for the stops are also applicable to the fricatives. In voiceless fricatives the glottis is wide open in the word-medial position (cf. Fig. 5.5.12);

3 As with the stops, the glottal opening for the affricate /ts/ is greater in initial position than in medial position.

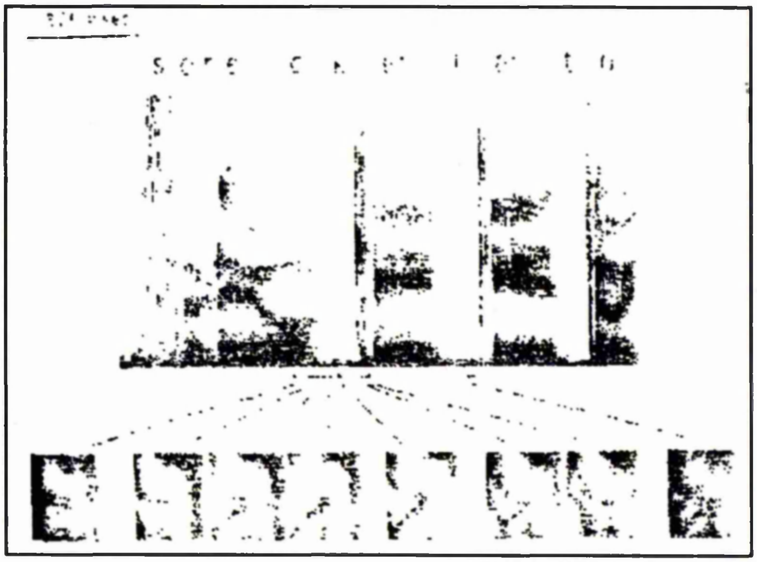


Figure 5.5.10. Selected frames of the glottal view for an utterance /ke:ke:/ corresponding to the speech signal in the frame sentence. Source: Sawashima et al (1976:410).

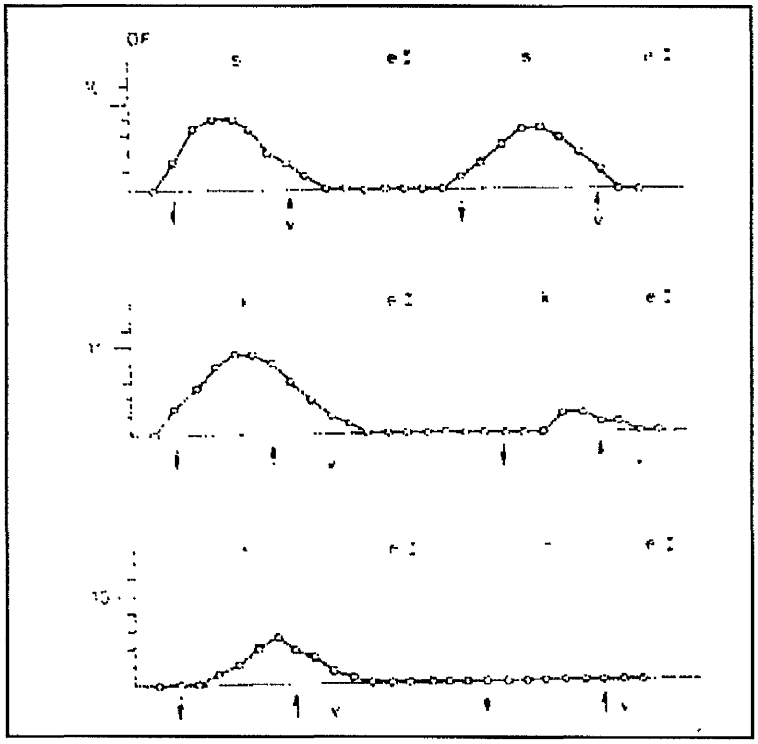


Figure 5.5.11. Opening and closing process of the glottis for voiceless consonants for all subjects.

Source: Sawashima et al (1976:412).

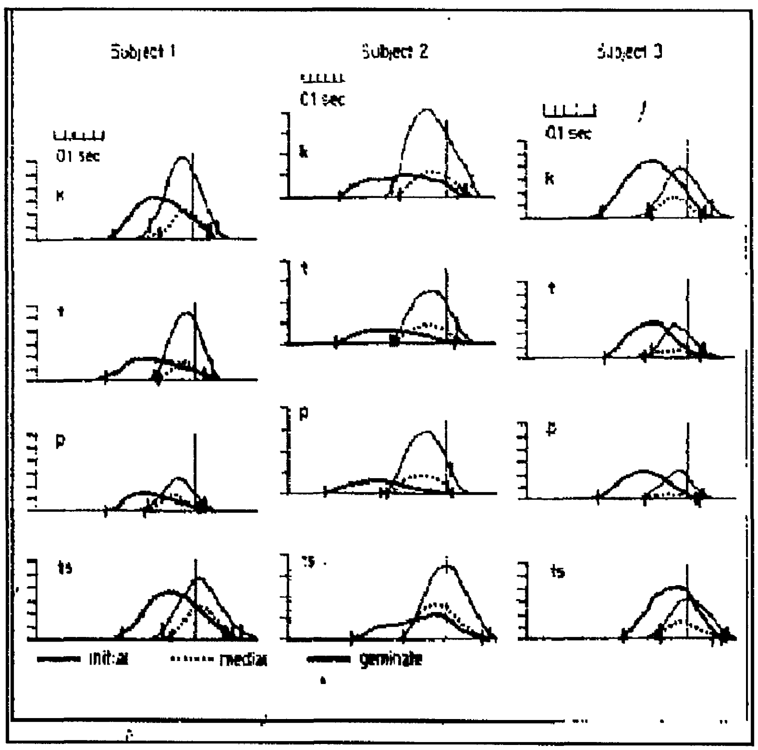



Figure 5.5.12. Averaged time course of the glottal opening and closing process for three subjects.

Source: Sawashima et al (1976:413).

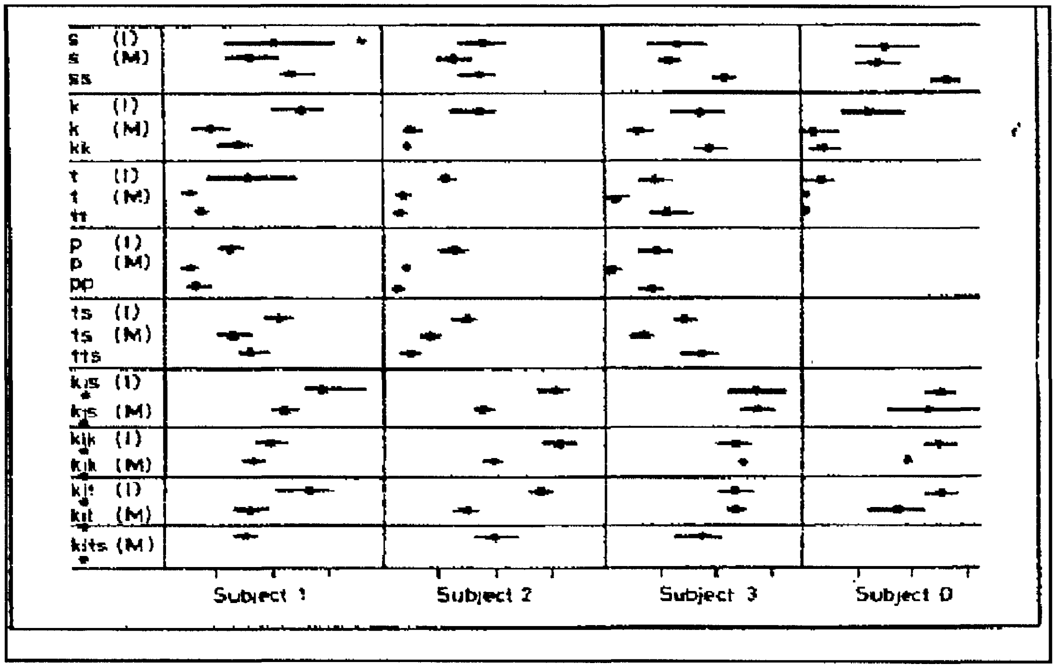



Figure 5.5.13: Maximum glottal aperture for the different consonants.

Source: Sawashima et al. (1976:412).

Note: the leftmost column of the figure (I) indicates word-initial position and (M) the -medial position. Horizontal bars in each item represent the entire ranges of the sample variation and filled circles indicate the mean values.

Similarly, Hirose and Ushijima (1978) investigated the laryngeal adjustments for the voicing distinction (voiced/voiceless) in Japanese consonant production in word initial and medial positions by means of fibreoptics in conjunction with electromyography (cf. section 5.10.3). A speaker of Tokyo dialect acted as subject and read a randomized list of test sentences sixteen times each. Each sentence embedded a test word in a frame. All test words used in the experiment were meaningful Japanese words.

In the experiment, the glottis was filmed during the production of the test words at a speed of 50 frames per second. Approximate frame sequences for the consonant pairs (voiced/voiceless) were examined frame-by-frame and analyzed with special regard to the time course of glottal aperture width as measured at the vocal process. A comparison between peak values of averaged PCA activity and glottal width was made in order to see whether there was any relation between the two parameters.

The authors reported their findings as follows:

1 Glottal width tends to be larger when the peak value of averaged EMG activity for PCA becomes higher and
2 There is a significant positive correlation between the two parameters (cf. Fig. 5.5.14 which shows the relationship between the results obtained by the two techniques).

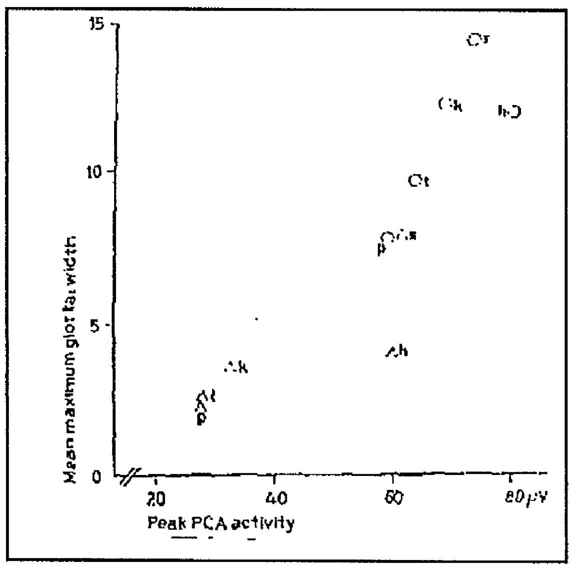



Figure 5.5.14. Relationship between the maximum glottal width (ordinate - arbitrary scale) and peak value of averaged PCA activity (abscissa).
O: word-initial voiceless consonants;
triangle: word-medial voiceless consonants.

Source: Hirose and Ushijima (1978:6).

## 5.6 X-ray.

### 5.6.1 Principles and Apparatus.

X-ray technique as a method for investigating speech mechanisms has been used to provide a permanent visual record. In principle, X-rays are similar to rays of light or heat. However, they can penetrate through objects which would absorb and reflect light. X-rays are usually produced when electrons strike any solid body, and special electron tubes are used to achieve this (Moll's 1965, Strenger's 1968 and Ball's 1984 accounts of X-ray technique form the basis of the account given here).

There are many specialist techniques using X-rays (see Ball 1984 for some of these and Nartey 1980 for a comprehensive bibliography of X-ray studies of speech). Here only a brief account is given of those used in studying the larynx in speech; for this purpose X-ray technique has often been used together with some other techniques (cf. Gleeson and Fourcin 1983, Noscoe et al. 1983 and Fourcin 1986).

Essentially, the apparatus consists of an X-ray generator capable of producing X-ray pulses, a control panel and an electron tube (through which the electrons produced pass). If a cinefluorographic X-ray is used, a high speed camera and film and an image intensifier may be included in the list of apparatus. The X-ray pulses are triggered using the generator. During photography, the subject is seated in front of the X-ray beam, behind a suitable metal shielding so that only the area to be investigated is exposed to the radiation. He is then asked to produce the desired sound. The operator then triggers the generator by pressing the camera shutter release and X-rays are recorded onto the photographic film. See Fig. 5.6.1 which is an illustration of the photographic equipment.

Although the general principles governing the use of X- rays are basically the same, there are several different specific techniques. Four main methods are usually distinguished. (No attempt is made to discuss all the variations of these techniques which could be utilized). The four methods are:

1 Still X-ray method.
2 Cine X-ray (cineradiographic) method.
3 Laminographic method.
4 Xeroradiography.

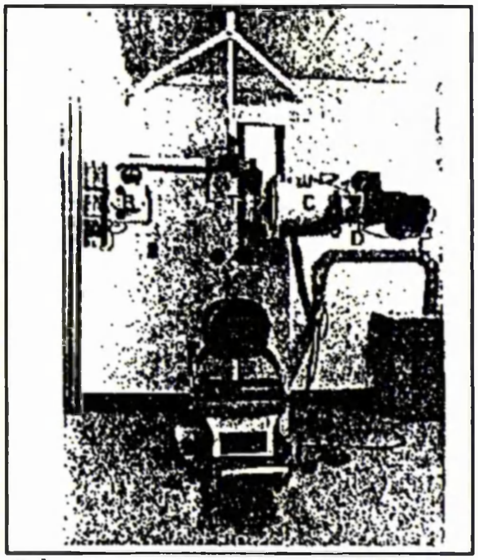


Figure 5.6.1. Illustration of Cinefluorographic equipment: A, X-ray tube; B, x-ray beam collimator; C, 9-inch image intensifier tube; D, fluoroscope viewer; E, Auricon, sound- on film, 16mm camera. Source: Painter (1979:204).

Of the four methods, the cineradiographic and the laminographic methods have been employed more extensively in speech research, although investigations have also been made using still photographic technique.

1 Still X-ray method: For this technique, the recording medium is simply a film sheet or a plate contained in a cassette holder. Sometimes an image intensifier is used in the cassette to enlarge the film exposure. The head of the subject is held in a fixed position during the production of a sustained speech sound and then the larynx is photographed.

2 Cine X-ray method: This technique is sometimes called serial photography. It provides motion pictures rather than still views of speech structures. The technique involves photographing the structures under

investigation several times in succession; the rate can be as fast as 12 exposures per second. When the image of the structures photographed is produced on a cine film the method is called **cineradiography.** Most cineradiographic equipment now in use involves electronic intensification of the X-ray image by factors of 1000-3000 times.

In the case of fluorography (cf. below) a motion picture camera, either normal or high speed, may be used; however, a television camera can be utilized to record image on video tape or to provide a television monitor display with subsequent photography of the monitor screen.

3 Laminographic method: For this method, the recording equipment utilized consists of an X-ray tube, an X-ray beam, an image intensifier and a motion picture camera for recording the image on film. Instead of positioning the X- ray source and the photographic film in one place, they are moved round continuously in a semi-circular arc in relation to the subject. In this way, only the area being investigated, which has maintained the same distance from the source and the film, will remain in focus. Thus, the technique usually provides a cross section of the structure because structures on all planes in the path of the X-ray beam are projected on the film, making visualization of tissue structures complicated. The technique, although used successfully in speech research, has the disadvantages of using a lot of film and a relatively high radiation dose.

4 Xeroradiography: This technique gives still pictures only. It uses a special plate, which avoids the necessity of using a photographic chemical plate. Pictures may be obtained immediately and the special

plate used again. The possibility of using the plate again has an added advantage particularly when on-going monitoring of pictures is needed, although it does require a high radiation dosage. Xeroradiography is particularly good at showing the relative densities of tissues.

## Direct and Indirect Techniques.

A division is sometimes made between direct and indirect X-ray techniques. The direct technique is called radiography, with X-rays recorded directly onto a photographic film or plate.

The indirect technique is called fluorography and involves photographing the X-ray image produced on a screen called a fluoroscope. Still, serial and cine film may be used to photograph the screen. The major problem in doing this is the sometimes rather low intensity of the image on the fluoroscope. The problem can usually be corrected by using an image intensifier.

## Quantification of the Results

If X-ray techniques are to be useful in speech research, they must provide accurate quantitative information. Still pictures have generally been analyzed by measurements of structural positions. In laryngeal studies, in order to be consistent in the measurement of the vertical movement of the larynx, the position is estimated in relation to a fixed reference point: it is usually measured from the upper edge of the 5th vertebral column.

In the case of motion pictures, analysis has often involved one or more observers viewing the film and describing what was seen. Such descriptions obviously represent a gross form of analysis of unknown reliability, particularly subject to observer bias. However, such observations can be much improved by centring attention on one structure or by using some type of rating scale (cf. McWilliams and Bradley 1963). Another method of analysis involves quantitative measurement of the motion picture films which requires taking measurements from individual frames. This can be laborious, but it has been demonstrated to be reliable (cf. Timcke et al. 1958, Smith 1960 and Fujimura 1961).

5.6.2 Advantages and Disadvantages of the Technique.

The technique has the following advantages:

1 It can be used with any subject as it does not require adjustments from subject to subject.
2 Unlike the traditional method of using a laryngoscopic mirror, the vibratory pattern of the vocal folds can be observed without interfering with phonational mechanism.
3 Unlike other photographic methods, e.g. laryngoscopy (cf. section 5.2.1), the technique can provide information about the structures above and below the level of the vocal folds during phonation, for example the distance between the thyroid and cricoid cartilages.

Disadvantages:

The method has the following limitations.

1 The investigator may have difficulty in accurately determining the edges of important soft tissue structures in the X-ray images. This problem however, can be overcome by Xeroradiography. This method allows a good view of soft tissues (cf. point 2 above).
2 Radiation can cause damage to vocal fold tissues and other tissues of the larynx and thus make the

technique potentially dangerous.

3 Still X-rays provide only one sample of the structures being examined and are thus very limited in providing information about any changing event. For example, the geometrical and time resolution is poor because the image is a kind of mean result due to the contributions of all the structures traversed by the X-rays during an exposure time, which is large compared with the vocal period.

4 Still X-rays are also limited in the sense that the use of still pictures requires that only speech sounds which can be sustained can be observed, since enough time for film exposure is necessary. This requirement therefore makes it difficult to observe vocal fold vibration.

5 The X-ray equipment is very expensive and complex, and requires medical supervision.

### 5.6.3 Comparison With Other Techniques.

Noscoe et al. (1983) investigated the movement of the vocal folds during phonation, using the X-ray technique in conjunction with the electrolaryngograph (cf. section 5.9.3). The electrolaryngographic output during the subject's phonation was used to trigger individual X-ray pulses at predetermined points in the Lx waveform cycles. In this way a series of images documenting vocal fold movement in normal phonation was observed. Seven subjects, 5 male and 2 female, were photographed. The aim was to allow the experimenters to observe the movement of the vocal folds during phonation.

Representative series of X-ray images showing the vocal fold movement during phonation were then examined together with the electrolaryngographic traces, beginning with the peak of vocal fold adduction via abduction phase to the onset of the next closure (cf. Fig. 5.6.2). Their observations were as follows:

1 Vocal fold movement is seen to be rolling during (modal) phonation.

2 The movements of the upper and lower borders of the vocal folds are out of phase except at times of peak opening and peak closure.

3 The X-ray images also show that in some subjects, phonation can be achieved without actual contact of the vocal folds.

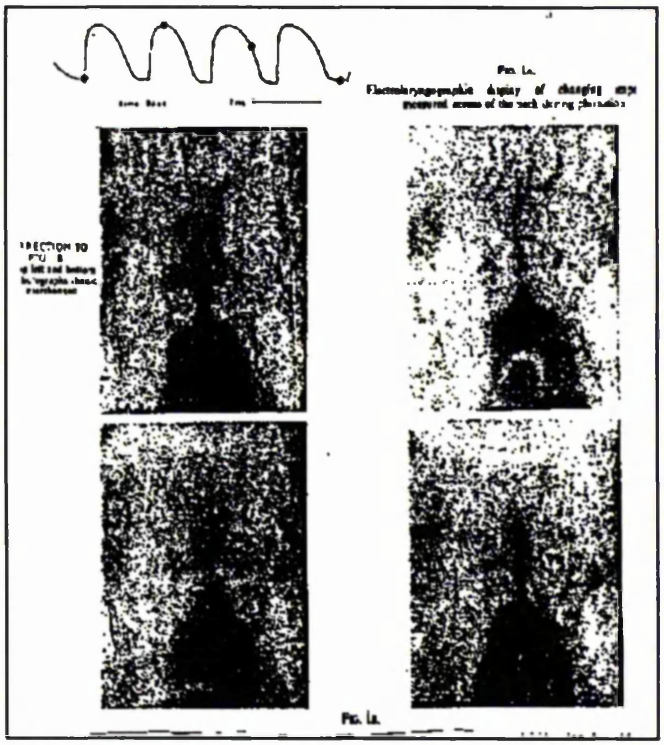


Figure 5.6.2. (a) Electrolaryngographic display of changing impedance measured across the neck during phonation, (b) antero-posterior radiographs taken using 30 nanosecond pulses at the position in the vocal fold cycle indicated by the dot on the electrolaryngographic sequence in (a). Source: Noscoe et al. (1983:642).

In a more recent paper, Fourcin (1986), using the X-ray technique in conjunction with electrolaryngography to observe the activities in a cycle of vibratory motion, has argued that there is an unambiguous correlation between the motion of the vocal folds as reflected in the Lx waveform and the X-ray images. See Fig. 5.9.12 and the discussion in section 5.9.3).

### 5.6.4 Some Applications of the Technique in Speech Research.

Damste et al. (1968) applied the X-ray method to obtain additional and clearer information on the relationship of (1) vocal fold length and (2) laryngeal tilt (i.e. cricoid-thyroid distance) to the variation in fundamental frequency of phonation during modal voice. Ten male subjects (free from any vocal disorders) were used to obtain data. They were photographed while phonating a sustained vowel at four different fundamental frequencies, 98, 131, 196 and 262Hz. The measurements of the authors led them to conclude that:

1 The vocal folds lengthen with increasing fundamental frequency. For example, they note that vocal folds increase in length by about 3.1 to 5.1mm, depending on which of the four fundamental frequencies is produced.

2 There is an inverse relationship between the distance from thyroid to cricoid cartilages and frequency of phonation. In other words, as fundamental frequency of phonation increases, the distance between thyroid and cricoid cartilages tends to decrease.

3 The X-ray technique provides an excellent method of observing and measuring laryngeal activities.

Hollien et al. (1968) undertook a study which observed the human vocal fold during phonation. They presented and discussed laminograms made of four male subjects phonating at four separate fundamental frequencies of 98, 124, 155 and 196 Hz. The subject's vocal range was determined in a screening session by having them match complex tones on an ascending and a descending scale. After a brief rehearsal the subjects matched a tone presented to them by earphone. The intensity of the vocal output was maintained by first asking the subjects to produce the selected pitch at "a comfortable level". The microphone gain was adjusted so that a subject's voice could trigger the X-ray mechanism.

In the study, measurements of (1) cross-sectional area and (2) thickness of the vocal folds were related to changes in fundamental frequency of phonation (cf. Fig. 5.6.3. which shows a tracing of lines used in obtaining coronal cross-sectional area and thickness measurements). After the basic outlines of the folds were made, they were measured for cross-sectional area by polar planimeter. The results of the cross-sectional area measures are displayed in Fig. 5.6.4. & 5.6.5). The resultant pictures of each experimental condition were examined and the ones showing closure were subjected to cross-sectional area and thickness measurements. See Fig. 5.6.6. which shows a series of stroboscopic laminograms giving the vibratory action of the vocal folds in coronal cross-section.

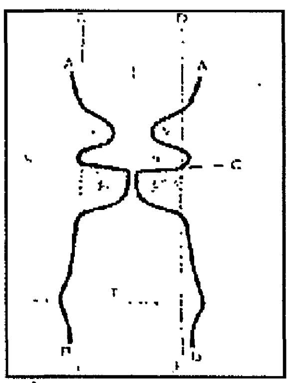


Figure 5.6.3. A tracing of a laminograph of the vocal folds showing the reference lines used in obtaining coronal cross-sectional area and thickness measurements.

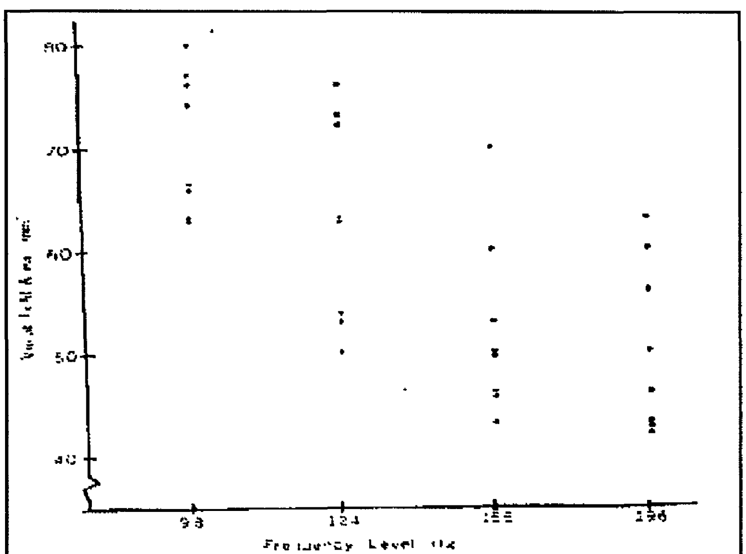


Figure 5.6.4. Scatter plots of cross-sectional area measures by frequency: there are eight data points at each of the frequencies.

The results of the study showed that area measurements for the four different frequency levels vary (cf. Fig. 5.6.5.), the general trend being that vocal fold cross-sectional area is inversely related to increase in fundamental frequency. Similarly the results for vocal fold thickness at the four different frequencies show the general trend to be that vocal fold thickness is inversely related to

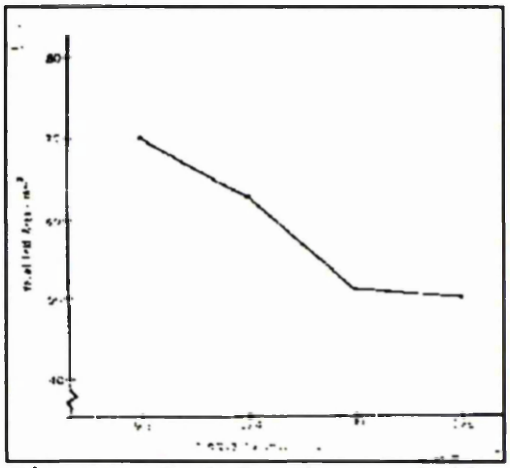


Figure 5.6.5. Mean of the area measurements for the four subjects.
Source: Hollien et al (1968:212-3).

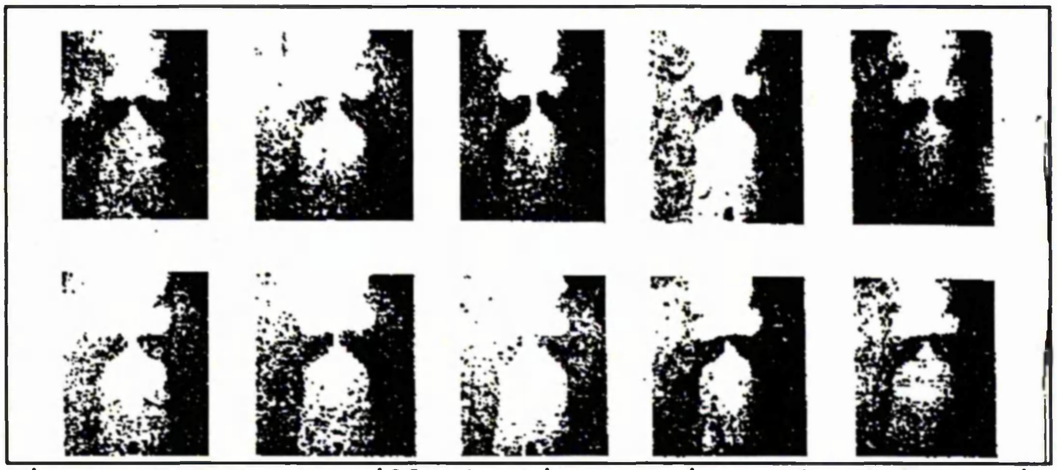


Figure 5.6.6. An illustrative series of stoboscopic laminograms showing the vibratory action of the vocal folds in coronal cross-section.
Source: Hollien et al. (1968:214).

frequency. See Figs. 5.6.7. & 5.6.8.) with regard to the thickness measures; it will be seen that there are several more data points per frequency level (cf. Fig. 5.6.7) than on the cross-sectional area measurements.

Fre Woldu (1985) devoted a chapter to X-ray technique and its application in laryngeal studies. He then presented a frontal cineradiographic study of the physiological adjustments made by the vocal folds and the vertical movement of the larynx during the production of Tigrinya ejective stops before the vowels [ i, e, I, a, o, and u] at the three different places of articulation - bilabial, alveolar and velar. The experimenter served as the only subject who was filmed. The cineradiographic camera speed was 50 frames per second.

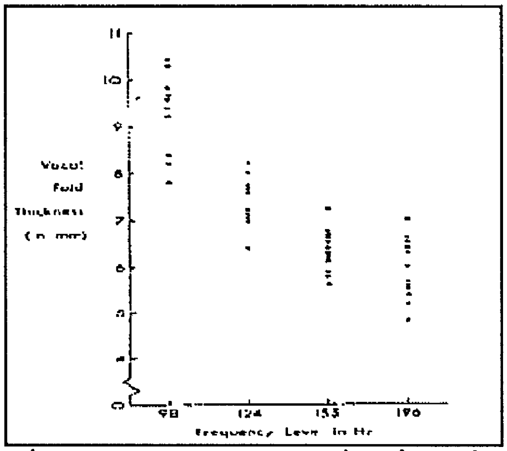


Figure 5.6.7. Variation in vocal fold thickness as a function of fundamental frequency.

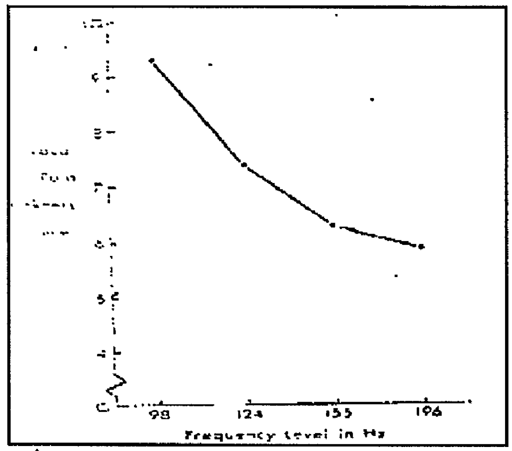


Figure 5.6.8. Mean of the vocal fold thickness measures.
Source: Hollien et al. (1968:213).

A frame by frame analysis of the film (which was traced by a Tage Arno frame-by-frame Analyzer) was then made. The height of the upper and lower edges of the vocal folds was measured relative to a fixed anatomical reference point (the upper edge of the 5th vertebral column). The vertical movement of the larynx was estimated in relation to half and one and a half times its height.

The experimenter took measurements from the fixed reference point along the following parameters:

1 The height of the upper and lower edges of the plica vocalis (true vocal folds), the level of the plica ventricularis (false vocal folds) angle, and the

bottom edge of the piriformis (mucous linings situated in the air column of the larynx), cf. Fig. 5.6.9). These measurements were made when the large surface contact was established, i.e. during the beginning of the occlusion phase.

2 The height of the upper and lower edges of the plica vocalis, the level of the plica ventricularis angle and piriformis sinuses during the maximal height of the larynx, i.e. the end of the rising phase.

3 The level of vibration of the following vowel, i.e, the end of the sinking phase (only the measures for the vowels i, a, and u were presented).

From these measures Fre Woldu found that:

1 The rising of the larynx during the articulation of the different ejective consonants and different vowel contexts does not begin from a common or neutral position. In general, the larynx has a lower position for bilabials than for dentals and velars. The kind of vowel following the consonant also has some effect on the larynx position (cf. Table 5.6.1).

2 The degree of vertical movement of the larynx varies according to the place of articulation, labials having larger movements than dentals and velars (cf. Table 5.6.2).

3 The normal larynx height during phonation was found to be variable depending wholly on the quality of the vowel following. The larynx in general has a higher position for /i/ and a middle value for /a/, with /u/ having the lowest values (cf. Table 5.6.3).

Table 5.6.1. Measurements in mm during the formation of a broad surface contact of the true vocal folds from a fixed reference point. Source: Fre Woldu (1985:119)

| Utterances | Plica Vocalis Upper | Plica Vocalis Lower | P. Ventricularis | Piriformis |
|---|---|---|---|---|
| pi | -4 | -9 | 5 | 0 |
| ti | 3 | -2 | 12 | 5 |
| ki | 1 | -4 | 10 | 5 |
| pa | -3 | -8 | 6 | 0 |
| ta | 3 | -2 | 12 | 5 |
| ka | 5 | 0 | 14 | 8 |
| pu | -10 | -15 | -1 | -8 |
| tu | -5 | -10 | 4 | -5 |
| ku | -5 | -10 | 4 | -5 |

Table 5.6.2. Measurements of the maximal height of the larynx in mm. Source: Fre Woldu (1985:120)

| Utterances | Plica Vocalis Upper | Plica Vocalis Lower | P. Ventricularis | Piriformis |
|---|---|---|---|---|
| pi | 10 | 5 | 17 | 15 |
| ti | 10 | 5 | 20 | 13 |
| ki | 13 | 8 | 22 | 17 |
| pa | 5 | 0 | 15 | 8 |
| ta | 10 | 5 | 15 | 15 |
| ka | 10 | 5 | 18 | 12 |
| pu | 0 | -5 | 6 | 3 |
| tu | 5 | 0 | 7 | 0 |
| ku | 3 | -2 | 10 | 5 |

Table 5.6.3. Measurements in millimetres of the level of the upper edge of the P. vocalis during the phonation of the following vowel.
Source: Fre Woldu (1985:121)

| Utterance | Level of P.Vocalis (mm) |
|---|---|
| pi | 5 |
| ti | 7 |
| ki | 10 |
| pa | 5 |
| ta | 5 |
| ka | 5 |
| pu | 0 |
| tu | 2 |
| ku | 3 |

From the sequences of film obtained, the author made the following observations:

1 The glottis is tightly closed at the onset of the occlusion phase and the entire larynx is constricted and drawn upwards (rises).

2 The maximum height of the larynx coincides with the moment of oral release.

3 At the moment of articulatory release, the larynx relaxes and sinks downwards while the glottis remains tightly closed. The glottis opens only 50-90 msec. after the moment of articulatory release.

4 The extent of the vertical movement of the larynx varies according to both place of articulation and the vowel context in which the stop is uttered.

Fre Woldu sums up his results with the general statement that the production of Tigrinya ejectives involves glottalization (tight closure of the glottis), larynx constriction, and raising and lowering of the whole larynx. See Fig. 5.6.10.

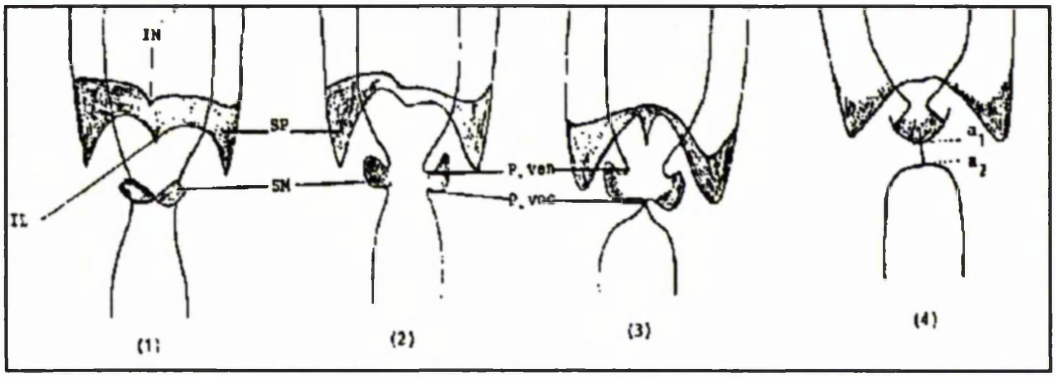



Figure 5.6.9. Frontal cineradiographic observation of four different configurations of the larynx: (1) expiration (2) before initiation of utterances (3) phonation and (4) glottalization. IN = interarytenoid notch, IL = interarytenoid line, Sp = sinus piriformis, SM = sinus Morgagni, P. Voc = Plica vocalis (true vocal folds), P. Vent. = Plica Ventricularis (false vocal folds), $a^1$ = upper edge of the true vocal folds and $a^2$ =lower edge of the true vocal folds. Source: Fre Woldu (1985:115).

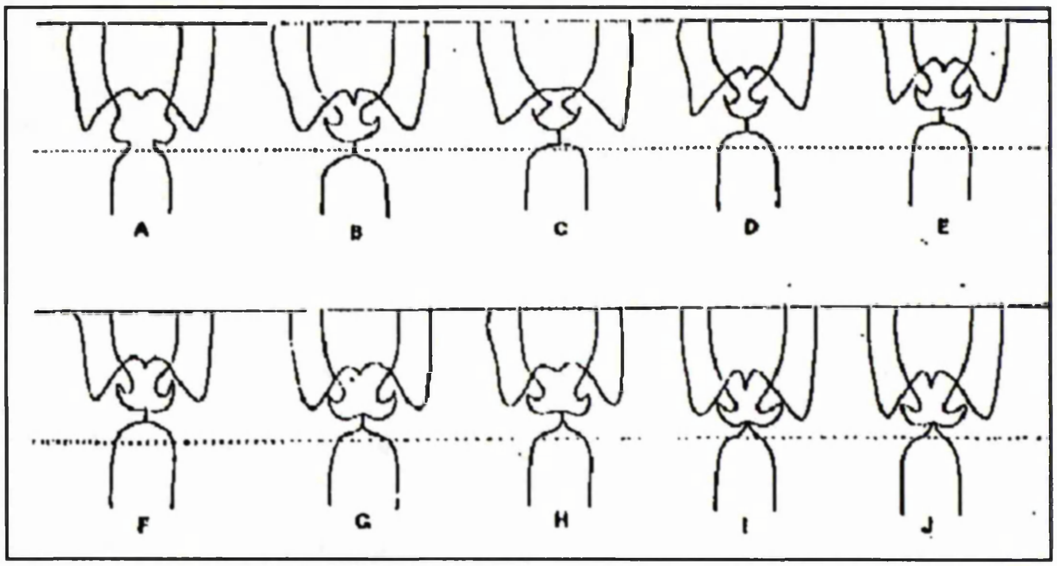



Figure 5.6.10. Frame by frame tracings of a frontal cineradiographic examination of the utterance /t̲a/. The sequences show the behaviour of the vertical movements of the larynx during the production of Tigrinya ejective stops. (A) Vocal folds make adduction movements. (B) The vocal folds touch each other over the entire surface. (C) and (D) The whole larynx rises. (E) Maximum height. (F), (G) and (H) Sinking and the vocal folds relaxing from the lower edge. (I) and (J) Configuration for vibration of the following vowel.

Source: Fre Woldu (1985:116).

## 5.7 Photo-electric Glottography (Transillumination of the Larynx)

### 5.7.1 Principles and Apparatus.

This method is used to record glottal area changes during speech. A strong light source is placed above or below the glottis. A photo-sensor placed on the opposite side of the larynx to the light source measures the intensity of the light passing through the glottis during phonation. The output of the sensor is then fed to a monitoring device such as an oscilloscope. There are various ways of obtaining permanent records of the variations in intensity, e.g. tape recorders and mingography (cf. section 5.13.1).

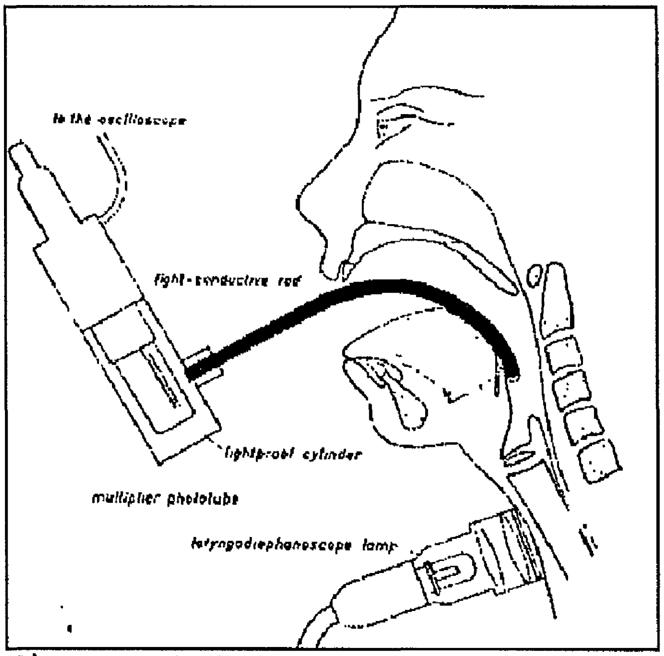


Figure 5.7.1:
Photoelectric method of studying the vibratory movements of the vocal folds.
Source: Sonesson (1960:67).

It is assumed that variation in light intensity reflects the variation in glottal area. The records of these variations constitute the photo-electric glottograms. When the vocal folds are opening the intensity of the light increases. During the closing movements of the vocal folds, the quantity of light decreases. During the time that the vocal folds are in contact with each other, the intensity of the light generally remains the same. See Fig. 5.7.1 for a set up of the recording technique.

Several other investigators have used this method, some modifying it slightly. Ohala (1966 and 1967) covered a small light sensor in a transparent plastic catheter. The light sensor was located about 25cm from the tip of the catheter which was inserted through the nose to the pharynx. A similar technique was also used by Frøjkjaer-Jensen (1967). Sawashima (1968) inserted a flexible fibrescope through the nose to obtain a motion picture of the larynx (during speech) simultaneously with the transillumination record. He introduced a light beam into the laryngeal passage via a fibreoptic bundle through the nose and illuminated the glottis from above, while a photo-sensor placed below the thyroid cartilage recorded the variable light passed through the glottis and the neck tissues (cf. also Lisker et al. (1969)).

### 5.7.2 Advantages and Disadvantages of the Technique.

Advantages:

1 The technique provides an indication of the vibratory behaviour of the vocal folds.

Disadvantages:

Coleman and Wendahl (1968:1735) and Hirano (1981:56) list the following as the sources of error:

1 The light-density distribution within the vocal folds may not be constant. Considering the changing cross-sectional area of the vocal folds in an anterior-posterior plane, there is no reason to expect that the subglottal (or supraglottal) light source will illuminate the folds evenly.

2 Light reflections from the mucosal surfaces may be

variable.

3 The method does not record the shape of the glottal opening, but merely the area. Consequently, one cannot make good inferences about the precise detail of the opening and closing mechanism.

4 Differences in location of the monitoring device may produce differing waveforms and sometimes a proper record of the glottal area is hard to obtain due to occasional fluctuations that might result from changes in the position of the larynx or jostling of the light by the epiglottis.

### 5.7.3 Comparisons with other Techniques.

To determine the applicability of the technique to the study of vocal fold motion, Sonesson (1960) compared it with high speed motion photography. The main objective was to compare the values obtained for the open quotient (OQ, i.e. the ratio of the duration of the open period to the duration of the entire cycle) using the two methods (cf. section 5.4 for UHS Photography). A second aim was to distinguish characteristic glottogram patterns for various intensities and pitches.

Twenty-five normal male subjects aged between 18 and 21 years were recorded reading the test material - the vowel /ä/ [ɛ̧] - at different intensities (low and high) and at five different fundamental frequencies (125, 175, 225, 275, and 325 Hz). Fifteen of the twenty-five subjects were first employed in a preliminary examination. On the ten other subjects, the vibratory pattern of the vocal folds was investigated under standardized conditions and measurements were made of the durations of the different parts of the vibratory cycle. The results were as follows:

1 The absolute duration of the open period of the vibratory cycle diminished with rising fundamental frequency, for example at a frequency of 125 Hz the duration was about 2.2 msec while at 325 Hz it had decreased to 1.2 msec.

2 The open quotient increased with rising pitch.

Statistically, there was significant inter-individual variation with regard to the relationship between OQ and fundamental frequency, i.e. the open quotient increased with rising fundamental frequency for all individuals but at different rates.

3 The speed quotient, which is the ratio between the durations of the opening and the closing movements of the vocal folds, was found to be independent of pitch (cf. also Timcke et al. (1958)).

4 The absolute duration of the open period diminished with increasing intensity and consequently the open quotient diminished too.

5 The speed quotient increased with increasing intensity, that is to say, the closing speed was increased in relation to the opening speed. Statistically, no significant inter-individual variation was found in this variable.

6 In the glottograms it was sometimes found, particularly at high fundamental frequencies (275 and 325 Hz), that the glottis was closed only momentarily, or incompletely, during the vibratory cycle.

7 The amplitude of the curves in the glottograms usually decreased with rising pitch. With increasing intensity, on the other hand, the amplitude was found

to increase, particularly at low pitches.

8 With increasing intensity the onset of the opening and the completion of the closing movements were more abrupt as was the transition from the opening to the closing movements.

9 Measurements of the duration of the various portions of the vibratory cycle obtained from high speed motion pictures were found to be similar to those obtained from glottograms. For example, a comparison of the open quotient values obtained from the two methods shows that they are of the same order of magnitude. See Table 5.7.1 which gives the time measurements of high speed motion pictures and that of the glottograms of the three subjects.

Table 5.7.1: Comparison between open quotient from glottograms and high speed motion pictures.
Tone intensity: high. Source: Sonesson (1960:67).

| Case motion | glottograms | high speed pictures |
|---|---|---|
| 1 | OQ= 0.61 (175 c.p.s) | OQ= 0.61 (156 c.p.s.) |
| 2 | OQ= 0.49 (225 c.p.s) | OQ= 0.54 (215 c.p.s) |
| 3 | OQ= 0.56 (174 c.p.s) | OQ= 0.61 (172 c.p.s) |

In another study Coleman and Wendahl (1968) recorded photo-electric glottograms simultaneously with Ultra High speed Motion Photography (cf. section 5.4.3) during sustained phonation at various fundamental frequencies. Four subjects were recorded. The subjects were simply asked to produce 'low' and 'high' pitches at comfortable loudness. Plots of glottal area function and photo-electric glottograms demonstrating the relationship between the two monitoring devices were made.

The glottal area function was determined by traditional polar planimeter methods, and the total area was plotted as a function of time. Secondly, the photocell output corresponding to the same glottal cycle was analyzed by measuring the deviation of the oscilloscope trace from the "no-signal" level. The amplitude and area curves thus derived were plotted as a function of time.

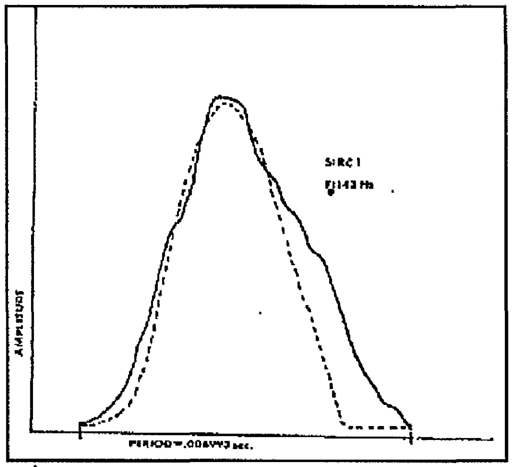


Figure 5.7.2. Plot of glottal area function (solid line) and photoglottogram (dotted line). Similarity of curves may be noted.
Source: Coleman and Wendahl (1968:1734).

For the purposes of illustration, the amplitudes of the photocell output and the glottal area function were normalized by equating their starting points and peak values as may be seen in Fig. 5.7.2 which illustrates a reasonable similarity between the photocell output and glottal area. When the authors compared the results of the two methods, they found that very little similarity existed between them. Of the eight conditions analyzed, six resulted in displays between the photocell and area functions that were dissimilar (cf. Fig 5.7.3 and Fig. 5.7.4).

The results made Coleman and Wendahl cast some doubt on the usefulness of the technique. They therefore conclude with the following remarks:

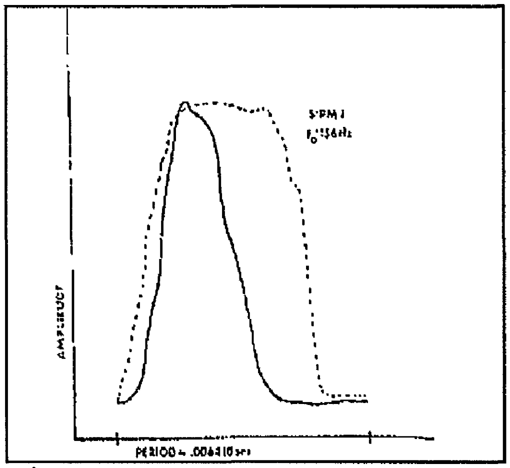


Figure 5.7.3. Plot of glottal area function (solid line) and photoglottogram (dotted line) demonstrating gross difference between the two monitoring systems.
Source: Coleman and Wendahl (1968:1735).

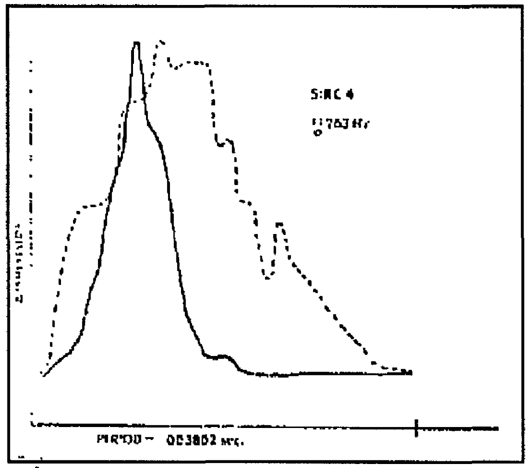


Figure 5.7.4. Plot of glottal area function (solid line) and photoglottogram (dotted line) demonstrating differences in indicated open time.
Source: Coleman and Wendahl (1968:1735).

> "Our conclusion, then, was that while photocell monitors, under controlled conditions, may provide an indication of laryngeal periodicity, relating waveforms thus derived to glottal area is not only hazardous but invalid in many cases... We suggest, however, that without acceptable validation of a procedure, the conclusions drawn from data thus obtained should be regarded with scepticism. In particular, arguing points related to spectral properties of the glottal wave seems tenuous, when such arguments are based upon results obtained by photosensor monitoring of the laryngeal source alone" (Coleman and Wendahl 1968:1734-35).

Both Minifie et al. (1968) and Holmer et al. (1975) have compared photoelectric glottgraphy and ultrasonoglottography. Their work is discussed briefly in section 5.8.3.

### 5.7.4 Some Applications of the Technique in Speech Research.

Lisker et al. (1969) presented a preliminary study which attempted to correlate features of the glottogram with articulatory events during the production of various English sounds. The transillumination technique was used in conjunction with acoustic pressure waveforms (recorded using a sensitive microphone) and intraoral air pressure waveforms. They compared the photo-electric glottograms obtained with the simultaneously recorded acoustic waveforms to determine how the voiced-voiceless distinction in English correlates with the open or closed state of the glottis.

The data described represents recordings from a single subject repeating the sentence **"Don't put a dirty tape around the tube"** (p:1545) selected to include English voiced and voiceless stops and fricative consonants in a variety of positions in running speech (particulary in medial position, cf. Fig. 5.7.5.).

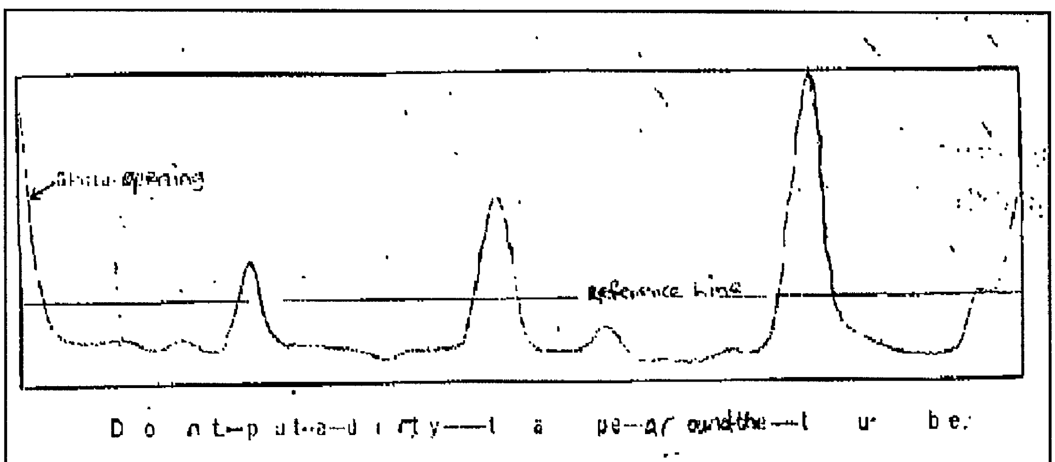



Figure 5.7.5: Glottogram of an English sentence. Greater transillumination, thus large opening of the glottis, is shown by upward movement of the trace.
Source: Lisker (1969:1545).

Sounds of ambiguous linguistic status, such as stops after /s/ and intervocalic flaps, were excluded from the study. The following parameters were examined:

1 Glottal aperture (opening) which causes the variation

in light registered by the photocell during speech, and

2 Glottal pulsing (pulsing feature i.e. interruption of voicing).

Observing the glottograms obtained, Lisker et al. noted that the voiced and voiceless categories can be distinguished on the basis of either presence versus absence of glottal opening or interruption of pulsing (cf. Tables 5.7.2 & 5.7.3). They concluded,

> "For 90% of a total of 321 consonant tokens recorded, the situation can be summarized as follows: (1) The voiceless stops were produced with either opening of the glottis or interruption of pulsing, or both; (2) the voiced consonants, both stop and fricative, were produced without interruption of pulsing; and (3) the voiced fricatives were produced with either an open or a closed glottis; this distinction generally matched the difference between fricatives of high and low noise intensity" (Lisker et al. 1969:1546).

As regards fricatives, a slightly more complicated picture emerged. The voiceless fricatives show glottal opening and interruption of pulsing for virtually all the items. In the voiced set, they observed a high percentage of items with open glottis and a few items with interruption of pulsing. In comparison with the stops, the fricatives appear to differ somewhat more sharply with respect to pulsing interruption than glottal opening (cf. Tables 5.7.2 & 5.7.3).

In another study, Dixit (1987, cf. also an earlier study, Dixit (1975)) presents some transillumination data on Hindi stops (cf. section 5.5.3 for a description of these consonants) and also refers to transillumination studies on many other languages (my main concern here is with Hindi; see Dixit (1987) for data and bibliography on the other languages). He investigated the dynamic glottal adjustments

Table 5.7.2: Distribution of stops and fricatives with respect to glottal opening and continuity of pulsing. Source: Lisker et al. (1969:1545-46)

| | Glottis | | Pulsing | |
|---|---|---|---|---|
| | % open | % closed | % broken | % unbroken |
| /b, d, g/ (N=60) | 6 | 94 | 5 | 95 |
| stressed (N=49) | 96 | 4 | 94 | 6 |
| /p, t, k/ | | | | |
| unstressed (N=57) | 84 | 16 | 84 | 18 |
| stressed (N=21) | 86 | 14 | 10 | 90 |
| /v?zz/ | | | | |
| unstressed (N=47) | 70 | 30 | 0 | 100 |
| /f?ss/ (N=72) | 99 | 1 | 99 | 1 |

Table 5.7.3: Combinations of conditions of glottal opening and pulsing for stops and fricatives. Source: Lisker et al (1969:1545-46).

| | Glottis | | Pulsing | |
|---|---|---|---|---|
| | % open | % closed | % broken | % unbroken |
| /b, d, g/ (N=60) | 6 | 94 | 5 | 95 |
| stressed (N=49) | 96 | 4 | 94 | 6 |
| /p, t, k/ | | | | |
| unstressed (N=57) | 84 | 16 | 84 | 18 |
| stressed (N=21) | 86 | 14 | 10 | 90 |
| /v?zz/ | | | | |
| unstressed (N=47) | 70 | 30 | 0 | 100 |
| /f?ss/ | 99 | 1 | 99 | 1 |

during bilabial plosives of the language. The subject was a male native speaker from the northern state of India, Uttar Pradesh. The subject read minimal pairs of monosyllabic and bisyllabic actual and nonsense words of the type CV, VCV, VC, where C represented the bilabial plosives /p/, /ph/, /b/ and /bh/, and V was the vowel /i/. The vowels following C in the CV words and preceding C in the VCV and VC words were stressed. All of the test words were embedded in meaningful sentences and read at a normal conversational level of pitch, loudness and speed.

A simultaneous recording of acoustic and photo-electric output was made. The light passing through the glottis was registered using a photo-electric glottograph (F. J Electronics Denmark), respectively (cf. Frøjkjaer-Jensen (1967) for a detailed description of the glottograph). The signal from the microphone and the photo-electric glottograph were simultaneously recorded on a FM data tape recorder (Honeywell 7600) as the sentences containing the test words were being read by the subject. The signals were later reproduced on paper by using an ink-jet oscillograph (Siemens Oscillomink, model E) for visual inspection and selection of tokens for measurements (cf. Fig. 5.7.6 ) for trace samples). A general purpose laboratory computer (PDP-12 from Digital Equipment Corporation) was utilized for measuring and averaging.

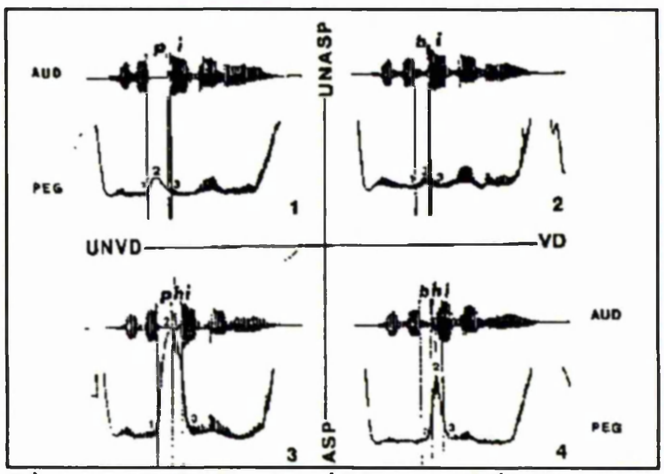


Figure 5.7.6: Oscillographic traces for the audio (AUD) signals and the photo-electric glottograms (PEG) for the test words /pi/, /bi/, /phi/ and /bhi/ spoken in a frame sentence. Source: Dixit (1987:53).

Each of these figures consists of four graphs containing two oscillographic traces. The top trace represents the audio (AUD) signal from the microphone and the bottom trace the signal from the photo-electric glottographic (PEG) signal. In the PEG signal, the upward and downward deflections of the trace indicated opening and closing gestures of the glottis respectively. The left half of these figures displays /p/ and /ph/ and the right half their counterparts /b/ and /bh/; the top half of these figures shows /p/ and /b/ and the bottom half their cognates /ph/ and /bh/. Hand-drawn vertical lines in each of the graphs of these figures mark certain articulatory or acoustic events. From left to right, the first line marks the approximate point of articulatory contact (AC) or the beginning of closure interval; the second line marks the point of articulatory release (AR) or the end of closure interval; and the third line marks the end of noise interval or the onset of the vowel (OV) following initial and medial plosives or the onset of the voiced segment occurring initially in the next word belonging to the carrier sentence. The numbers 1, 2 and 3 on the PEG traces indicate the initiation of the glottal opening gesture (IGO), the peak of glottal opening (PGO) and the termination of the glottal closing gesture (TGC), respectively.

Selected tokens of each of the utterances were used to measure time intervals between certain glottal and articulatory events indicated by the numerals on the PEG curves and vertical lines drawn through AUD signals and PEG curves. The following measures were made:

1 time interval between initiation of glottal opening and articulatory contact;
2 time interval between peak of glottal opening and articulatory contact;
3 time interval between peak of glottal opening and articulatory release;
4 time interval between termination of glottal closing and articulatory release;
5 time interval between termination of glottal closing and vowel onset;
6 duration of closure interval (DCI);
7 duration of noise interval (DNI);
8 height of the peak glottal opening (PH).

Table 5.7.4: Average time intervals of glottal events for /p/, /ph/, /b/, /bh/.
Source: Dixit (1987:57).

| | Intervals Between | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Plosives | IGO | PGO | | TGC | | | | | |
| | AC | AC | AR | AR | OV | | DCI | DNI | PH |
| 1 | 2 | 3 | 4 | 5 | 6 | | 7 | 8 | 9 |
| Initial | | | | | | | | | |
| /p/ | 16 | -64 | 60 | -40 | -24 | | 124 | 16 | 06 |
| /b/ | No light passing through the glottis registered | | | | | 88 | 00 | 00 | |
| /ph/ | 18 | -92 | 00 | -120 | -60 | | 92 | 60 | 37 |
| /bh/ | -40 | -112 | -32 | -118 | -62 | | 80 | 56 | 19 |
| Medial | | | | | | | | | |
| /p/ | No light passing through the glottis registered | | | | | 120 | 10 | 00 | |
| /b/ | No light passing through the glottis registered | | | | | 92 | 00 | 00 | |
| /ph/ | 12 | 92 | 08 | -92 | -44 | | 100 | 48 | 25 |
| /bh/ | -44 | 92 | -24 | -100 | -52 | | 68 | 48 | 13 |
| Final | | | | | | | | | |
| /p/ | No light passing through the glottis registered | | | | | 120 | 00 | 00 | |
| /b/ | No light passing through the glottis registered | | | | | 60 | 00 | 00 | |
| /ph/ | 20 | -72 | -08 | -104 | -32 | | 64 | 72 | 22 |
| /bh/ | -16 | -68 | -20 | -104 | -40 | | 48 | 64 | 11 |

Results were presented in the form of numerical data and graphs (cf. Table 5.7.4.), showing quantitative data in the form of averages based on 15 to 20 measures of time intervals in milliseconds between initiation of glottal opening gesture (IGO) and articulatory contact (AC) (column 2), peak of glottal opening (PGO) and articulatory contact (AR) (column 3), peak of glottal opening (PGO) and articulatory release (AR) (column 4), termination of glottal closing gesture (TGC) and articulatory release (AR) (column 5), and termination of glottal gesture (TGC) and onset of vowel (OV) (column 6) for the different manner categories of initial, medial and final bilabial plosives. Columns 7 and 8 show the mean durations of the closure interval (DCI) and the noise interval (DNI) respectively. Column 9 shows the peak heights (PH) of glottal opening. A negative value indicates AC, AR, or OV preceding a related point,such as IGO, PGO, TGC, on the PEG curves.

Figure 5.7.7 shows variations in glottal area (GA) as a function of time and heights of peak glottal opening shown along the ordinate in arbitrary scale, and time is shown along the abscissa in milliseconds (ms). Solid curves represent /ph/, dashed curves represents /bh/ and dotted curves represent /p/. No curves are shown for /b/ and the word medial and final /p/ since little or no light passing through the glottis was registered during their production. The curves were aligned in relation to the instant of articulatory release. The top panel of the figure displays the glottal area curves for the initial plosives, the middle panel for the medial plosives and the bottom panel for the final plosives. Numerals 1, 2 and 3 on the glottal area curves are the same as those on the PEG curves on Fig. 5.7.6, namely initiation of glottal opening, peak of glottal opening and termination of glottal closing and termination of glottal closing gesture, respectively. Short vertical lines on the glottal area curves of the voiceless plosives mark the cessation of voicing continuing from the preceding voiced environment into the early part of the closure interval. The glottal area curve in this figure is also the basis for the timing relationship in Table 5.7.4.

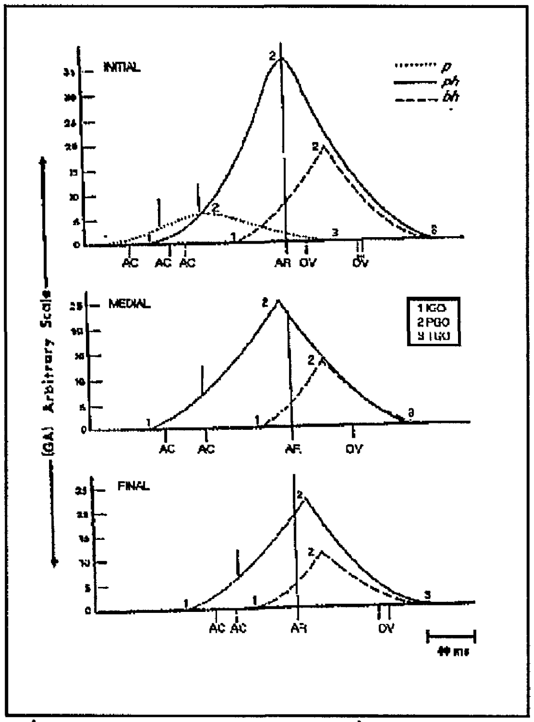


Figure 5.7.7: Superimposed GA (glottal area) curves comparing temporal course of glottal dynamics with respect to supraglottal articulatory adjustments for different manner of plosives.
Source: Dixit (1987:59).

On the basis of the data in Table 5.7.4. and Figure 5.7.7. the author reports the following findings concerning Hindi stops:

1 /b/ is generally produced with an approximated glottis and vibrating vocal folds throughout the closure interval;

2 /p/ may be produced either with an open or an approximate glottis but non-vibrating vocal folds. When it is produced with an open glottis, the glottis generally begins to open somewhat prior to the articulatory contact or closure, peaks at or near the middle of the closure interval and closes at or immediately after the articulatory release;

3 /bh/ is produced with an approximated glottis during part of the closure interval and with an open glottis during part of the closure interval and all of the noise interval. The glottis generally begins to open around the middle of the closure interval, peaks around the middle of the noise interval and closes well after the articulatory release during the early part of the following voiced segment;

4 /ph/ is produced with a wide open glottis and quiescent vocal folds. The glottal opening is generally initiated somewhat earlier than the articulatory occlusion, the peak of opening occurs at or around the instant of articulatory release, and the glottal closure occurs well after the articulatory release during the initial portion of the following voiced segment;

5 The timing of the initiation of the glottal opening gesture in relation to the articulatory closure is generally similar for /p/ and /ph/ but different for /bh/. The timing of the completion of the glottal closing gesture in relation to the articulatory release is generally similar for the /bh/ and /ph/ but different for /p/ and the timing of the peak glottal opening with respect to the articulatory release is different for all three types of stops;

6 The degree of glottal opening decreases in order from

/ph/ to /bh/ and then to /p/. The glottis is wide open during /ph/, moderately open during /bh/ and narrowly open during /p/ stop.

7 For those stops that are produced with an open glottis, the degree of glottal opening was greater in the word-initial prestressed position than in the word-medial poststressed and word-final poststressed positions; in the latter two positions, the word-medial stops showed a somewhat greater glottal opening than word-final stops;

8 The degree of glottal opening does not seem to be systematically related to either the extent of the duration of closure interval or the extent of the duration of noise interval;

9 No apparent direct correlation between the degree of glottal opening at the instant of articulatory release and the degree (duration) of aspiration (noise interval) is observed;

10 Voicing and aspiration are laryngeally controlled in the sense that they are both generated at the glottis and the glottis is adducted for voicing and abducted for aspiration.

## 5.8 Ultra Sound Glottography (Ultrasonoglottography, Echoglottography).

### 5.8.1 Principles and Apparatus.

The technique was first developed by scientists at Chiba University (cf. Asano 1968, Kitimura et al. 1967). See Hamlet (1981) for a comprehensive review of the literature on the use of ultra sound for studying the vocal fold as well as ultra sound instrumentation. With this technique, continuous high frequency sound waves (ultrasonic waves) are passed through the larynx as a means of monitoring vocal fold motion during speech production. The transmitted ultrasound beam is picked up by a receiving transducer and converted into an electrical signal. The signal is then passed into an amplifier. The amplified signal may then be displayed on an oscilloscope and recorded for analysis. The technique presents no discomfort to the subject as no instrument is inserted in his oral or nasal cavity. Using the method one can determine the fundamental frequency during normal speech.

The system works on the theory that high frequency waves can be transmitted through different kinds of media, including body tissues. They will always be reflected at the interface between two media which differ in specific acoustic impedence. The acoustic impedence is the differential product of the thickness of the body and the speed of the sound through it (cf. Hirano 1981:59).

Two transducers (used as transmitter and receiver) are placed on either side of the neck and held in place by a rubber band. Variation of the ultrasound intensity transmitted between the two transducers through the vocal fold level during the closed phase is recorded simultaneously on a display. The waveform obtained is called a "sonoglottogram" or "ultrasound glottogram"

(Hirano 1981:59). It reflects the glottal condition during both the open and closed phases (cf. Fig. 5.8.1).

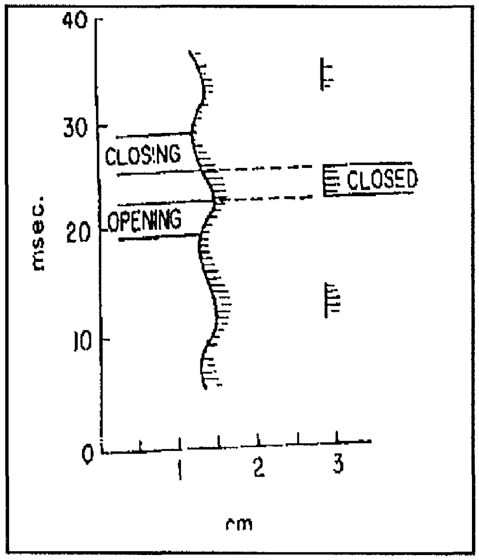



Figure 5.8.1: Example of an acceptable ultrasonic signal received through the vocal folds, after rectification and demodulation (lower waveform). About 3 1/2 vibratory cycles are shown. During the open phase no ultrasonic signal is received, if the transducers are correctly positioned.
Source: Hamlet (1981:132).

Holmer et al. (1975) describe the basic instrumentation employed and the theoretical principles underlying the technique in the following way:

> "Applied at each side of the neck, two matched ultrasound piezoelectric crystals, i.e, transducers made of barium titanate (Phillips PXE5), are used as transmitter and receiver. Between these transducers a continuous ultrasonic wave propagates through the larynx from the transmitting to the receiving transducer. When the vocal folds are open, the intensity of the ultrasound passing through the air-filled glottis is low. This depends on the fact that the acoustic impedence of air is much smaller than that of the surrounding tissue and, consequently, strong reflections from the surface of the vocal folds are to be expected. However, when the vocal folds are in contact with each other within an unbroken ultrasound beam, the ultrasound passes through the contact surface. The intensity transferred changes with the variation of the contact of the vocal folds. This variation of the received ultrasound intensity is recorded during speech (or phonation) and is proportional to the fundamental frequency of the vocal folds" (Holmer et al. 1975:1073).

The ultrasonic signal is demodulated by the receiving transducer and converted into an electric signal which is fed into the receiving unit for investigation of the curve

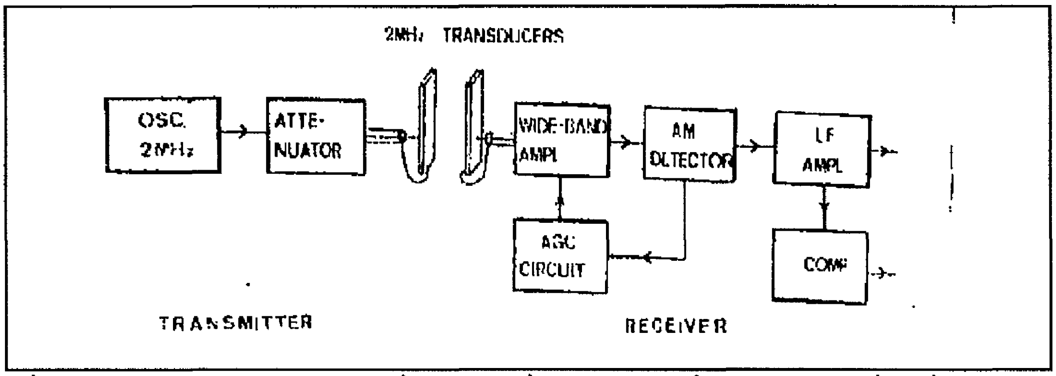



Figure 5.8.2: Block diagram illustrating the principle of the apparatus.
Source: Holmer and Runqvist (1975:1074).

shape. See Fig. 5.8.2 which shows the complete set of the unit.

5.8.2. Advantages and Disadvantages of the Technique.

Holmer et al. (1975:1074-76), Holmer and Reid (1972) and Hirano (1981:59) list the following advantages of the technique.

1 The technique utilizes electric equipment which is simple and portable.

2 The ultrasound technique offers a suitable alternative that is comfortable for the subject as only external sensors (detectors) are in contact with the subject. Vocal fold motion can be monitored quite easily during production of all speech sounds without obstruction of the articulatory organs.

3 Data collection with the unit is rapid, safe and can be accomplished with inexperienced subjects.

4 The open and closed periods of the vibratory cycle of the vocal folds can easily be determined by this technique.

The following have been found to be the main problems with the method (cf. Minifie et al. (1968), Holmer et al. (1975:1073 and 1076) and Hirano (1981:59)).

1 Correct placement of the transducers is sometimes problematic. If the transducer's position is wrongly chosen, signal information will not be correct; there will be less transmission and consequently, the signal disappears or becomes hardly noticeable.

2 A false amplitude-modulated signal may arise if the contact surface between the transducers and the neck varies. This happens when transducer pressure is too loose.

3 False signals may also be caused by the fact that other parts of the larynx also vibrate during speech (These signals mostly have the same frequency as the fundamental frequency).

4 Continuous displacement (i.e. up and down movement) of the larynx relative to the transducers can cause poor transmission signals.

5 Damage can be caused to larynx tissue by too much ultrasonic beam passing through the skin and further through the glottis. In other words a cumulative radiation dose to the subject is harmful.

6 Correct interpretation of the data obtained is not always simple.

### 5.8.3 Comparisons with other Techniques.

To test the validity of the technique in the study of vocal fold motion, Minifie et al. (1968) carried out a number of studies, utilizing freshly excised animal larynges, (cf. Minifie et al. 1968:1165-1166 for the arrangement of the experiments) simultaneously with Photo- electric glottohraphy (transillumination, cf. section 5.7.3). The synchronous display of both the ultrasound signals and transillumination signals provides an indication of which part of the ultrasound pattern corresponds to vocal opening and which to closing. The transmitted signal was observed on an oscilloscope and photographed using UHS photography. The photographs obtained were then analysed to determine the characteristic pattern of the vocal fold motion.

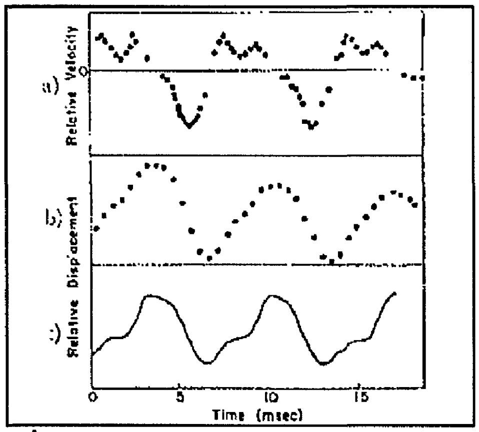



Figure 5.8.3:
(A) Velocity curves
(B) The relative vocal fold displacement curves
(C) A glottogram is simultaneously presented.
Source: Minifie et al. (1968:1167).

The authors also presented results of a typical ultrasound read-out observed when monitoring human laryngeal function during phonation. One of the researchers acted as the subject, phonating at a normal conversational level with a fundamental frequency of 157Hz. They then analyzed the characteristic patterns to obtain information concerning the motion of the vocal folds was then made. By measuring the instantaneous period averaged over one cycle of the ultrasound frequency signal, the vocal fold velocity as a function of time was calculated. The agreement between the curves obtained from the two methods were found to be very good. The authors also observed that the Doppler displacement curves (the ultrasonic Doppler velocity monitor is based on the frequency shift produced by a moving source or observer) were very similar to the displacement data obtained from the high speed motion picture films of Timcke, v. Leden and Moore (1958) and they show good correlation with other methods of measuring vocal fold motion and glottal area.

The authors report that, on comparison, the results obtained when monitoring the human larynges show great similarity to those obtained using excised animal larynges (illustrations were not given). They therefore conclude that the technique is successful in studying vocal fold motion.

Beach and Kelsey (1969) reported another study which was made to test the validity of the ultrasound Doppler technique described by Minifie et al. (1968). They compared simultaneously recorded ultrasound signals obtained from the region of the vocal folds and associated laryngeal imaging of the folds as it appeared on the frames of the high speed motion film to see how well the ultrasonic signals correlated with the actual vocal fold motion during phonation (cf. section 5.4.3). A male subject was recorded while producing the vowel [a] at a fundamental frequency of 217Hz. The procedure for correlation of the ultra sound signals with the associated vocal fold motions consisted of photographing an oscilloscope presentation of the ultra sound signal and a standard laryngoscopic image of the vocal folds simultaneously on high speed film. Frame rates of 2000 to 3000 frames per second were used to capture the rapid motion of the folds and two 45 degree prisms with independent lens systems were used to present both images to the camera. Each frame of the high-speed

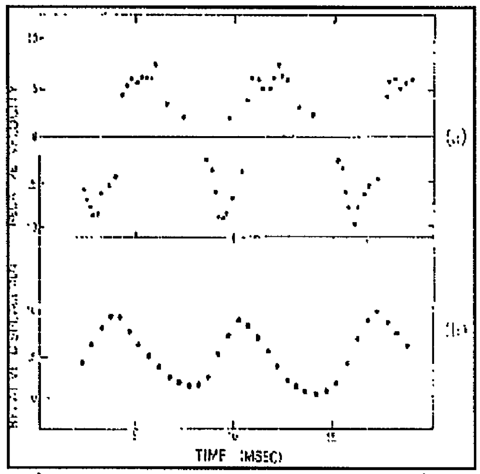


Figure 5.8.4: Relative vocal fold velocity (upper trace) and the relative displacement (lower trace) patterns from human subject during phonation.
Source: Minifie et al. (1968:1168).

film contained an image of the vocal folds and a section of the ultra sound signal present during the exposure time of the frame. The correlation was made by comparing the ultrasound sections with the vocal fold images. For greater accuracy, velocity calculations were made from a continuous tape recording of the ultra sound signal. Thus, associated with each ultra sound section (signal) was a calculated velocity and displacement of the vocal folds and a measurement of the actual opening of the glottis made from the film. Figure 5.8.5 is an illustration of the data obtained from the two methods. From the results obtained the authors concluded that the relationship between recognized ultrasound frequency pattern and the corresponding motions of the vocal folds is both inconsistent and ambiguous.

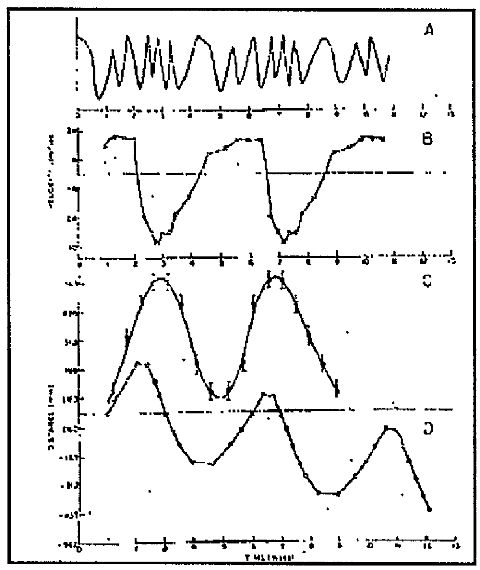



Figure 5.8.5: Comparison of actual and calculated vocal fold motion, where (a) is the Doppler signal whose frequency is proportional to velocity (b) is the calculated velocity, (c) is the actual diplacement of the folds from the midline, measured from laryngeal films, and (d) is the calculated diplacement. Source: Beach and Kelsey (1969:1046).

Further tests of the applicability of the method were carried out by Holmer, Kitzing and Lindström (1973) and Holmer et al. (1975). Holmer, Kitzing and Lindtröm (1973) studied four subjects varying in age and sex but having equally thick laminae (83 and 43 year old males, 75 and 63 year old females). Measurements were made by obtaining echoes with the transducer directed at the anterior edge of the thyroid laminae and at its centre. The aim was to study the ability of ultra sound to penetrate cartilages with varying degrees of hardness by measuring the amplitude alternation of different frequencies. The measurements of the ultra sound echoes were recorded by a time motion technique (cf. Fig. 5.8.6 which shows the principle of this technique). Transducer signals of 2, 4 and 6 MHz were analysed. The authors also reported the use of an improved ultra sound reflectroscope which was especially adopted for recording of the movements of the vocal folds, using a pulse repetition frequency of 10,000Hz. A block diagram of the apparatus is shown in Fig. 5.8.7. For a detailed description of the device see Holmer, et al. (1973:456-9).

The authors noted that the ultrasonic attenuation was consistently less when the beam passed through the centre of the thyroid lamina and, as expected, was less for the lower ultrasonic frequencies used. In the male specimens it was not possible to use the 6MHz frequency at the anterior placement. In male larynges the attenuation was greater than in female larynges, a fact which the authors attributed to hardening of the cartilages.

The authors felt it should be possible to use ultra sound for laryngeal study, even in the presence of ossification of the cartilages, if the frequency used were low enough and the beam were directed through the central region of the thyriod lamina.

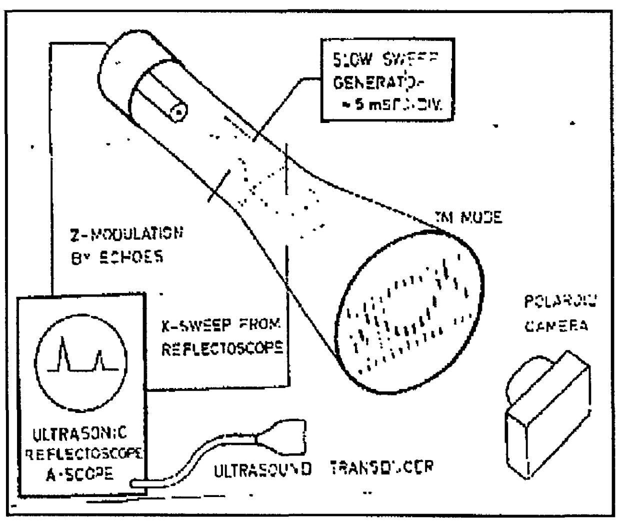
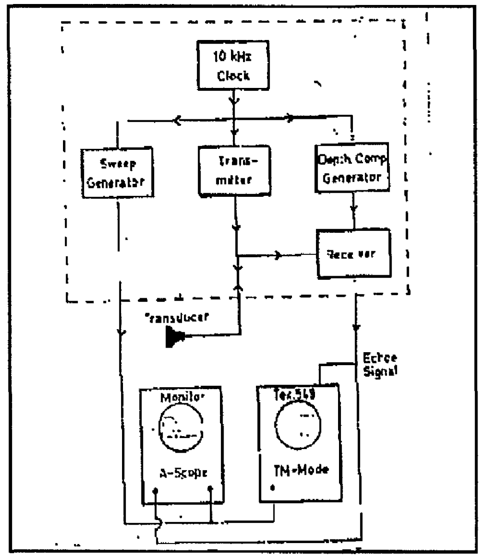



Figure 5.8.6: Principal diagram of the TM-recording method in which the echo-glottographic recording of the vibrating vocal folds are directly displayed on the screen of a cathode ray tube photographed with a Polaroid camera. Source: Holmer et al. (1973:457).

Figure 5.8.7: Block diagram of especially constructed reflectroscope for echoglottography, including a monitor oscilloscope for A-scope and a storage oscilloscope for TM-display.
Source: Holmer et al (1973:458).




In a later report Holmer et al. (1975) recorded four subjects, 3 male and 1 female, producing sustained phonations using different transducer positions on the neck (recordings were made at nine different locations on the neck around the level of the vocal folds, (cf. Fig. 5.8.8) and at different frequency levels of the voice: for example, a normal fundamental frequency of about 125Hz, with transducer in the correct position, and high fundamental frequency of about 200Hz. The ultrasound recordings were made together with photo-electric glottographic recordings (cf. Fig. 5.8.9; see also section 5.7.3). Holmer et al. noted that the ultrasound transmission varied in amplitude depending on the location of the transducers on the neck (cf. Fig. 5.8.8). This time, the authors judged the Doppler method as unsatisfactory for the study of vocal fold vibrations.

Thus, there is some question as to the validity of results obtained using ultrasonoglottography. The technique has not been much used in linguistic research.

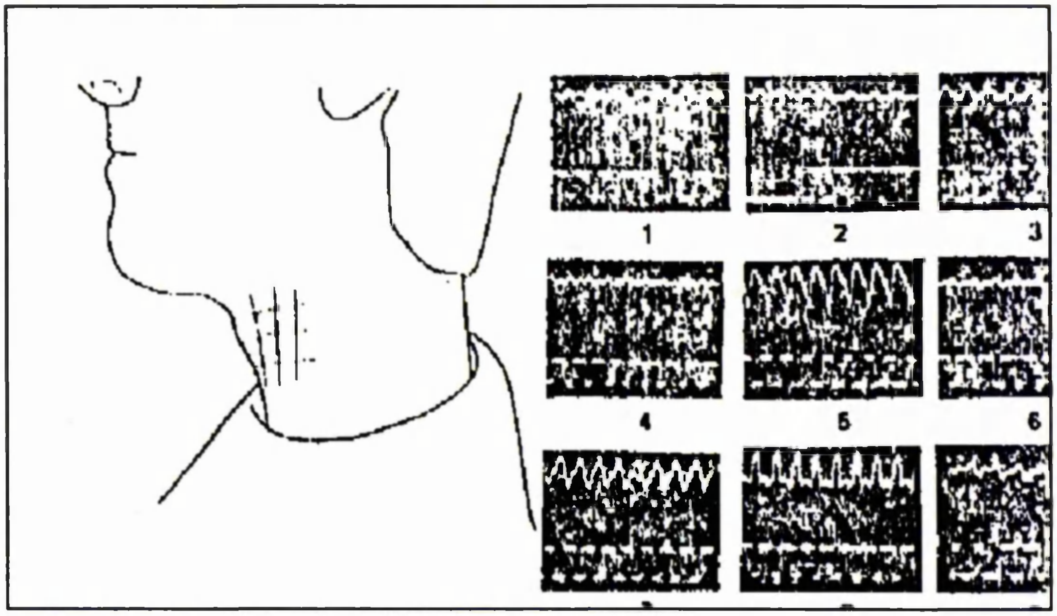
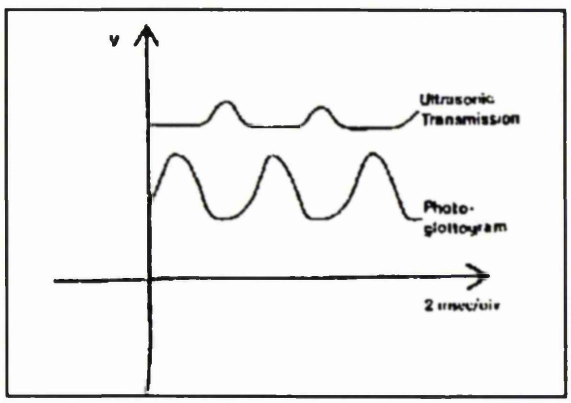



Figure 5.8.8: An investigation at nine points on the neck around the level of the vocal fold. The scanning points are numbered from 1 to 9. Every square has a side with a length of about 1 cm. At the intersection between the lines the center axis of the transducer arrangement was applied. Source: Holmer et al (1975:1076).

Figure 5.8.9: A simultaneous recording of vocal fold vibrations with ultrasound transmission and photoglottographic methods. Source: Holmer et al (1975:1076).



## 5.9 Electrolaryngography (Electroglottography)

### 5.9.1 Principles and Apparatus.

> "Electrolaryngography is a non-invasive technique based on the monitoring of the varying electrical impedance of the vibrating vocal folds by means of two gold-plated guard ring electrodes superficially applied to the skin of the neck on each wing of the thyroid cartilage" (Fourcin and Abberton (1984:64)).

Fabre (1957) first introduced the electrical impedance measurements to the study of the larynx; he had previously applied the technique to observation of pulsatile arterial blood flow (cf. Fabre 1940). He named his device the **glottograph** and its output (waveform) the **glottogram.**

In his original work Fabre's interpretation of his waveforms indicated that he believed that glottal aperture variation was being monitored but as pointed out by several workers later (e.g. Fant et al. 1966) the Fabre glottograph gives an indication of the events during glottal closure. Similarly, the Fourcin, Donovan and Roach (1971) study (based on Fourcin's laryngograph) confirmed that glottal aperture variations do not contribute significantly to the output of the impedance monitoring arrangement and that the electrical output is only really significant during the period of vocal fold closure. A similar study by Donovan and Roach (Fourcin 1974a:317-319) emphasized the detail of Lx response during vocal fold closure. It is for this reason that Fourcin 1974a and 1986, and Fourcin and Abberton 1971 call his impedance monitoring device a **laryngograph.** It is Fourcin's laryngograph that is the basis for the research techniques employed in this present study and it is described in detail below.

Since Fabre (1957), improvements in the apparatus and application of the technique have been made, mainly by researchers from Europe, and recently the technique has become more popular in the United States (cf. Fant et al. (1966), Childers, Hicks, Moore and Alsaka (1986), and Childers, Smith and Moore (1984)). Both terms, "glottograph" and "laryngograph" are currently in use. The difference in terminology is often, though by no means always, associated with a difference in presentation of the output. "Glottogram" typically refers to presentations in which the peaks represent minima of contact and the valleys maxima of contact. In a "laryngogram" the position is reversed; the peaks represent maxima of contact and the valleys minima of contact.

5.9.1.1 Fourcin's Laryngograph.

The operation of the laryngograph has been described by Fourcin (1974a), Fourcin and Abberton (1971 and 1976), Gilbert et al. (1984) and Abberton et al. (1989). My discussion of the technique is based on these sources, which also describe the derivation of fundamental frequency (Fx) from the output of the laryngograph. Fx is the measure of the instantaneous frequency derived from the observation of successive closure periods.

The device operates by measuring the electrical impedance across the laryngeal area by means of two electrodes which may be tied with an elastic supporting neck-band round the neck of the subject (cf. Fig. 5.9.1). Each electrode consists of a gold-plated copper disk enclosed in a gold-plated copper guard-ring. The electrodes are positioned at the level of the


Figure 5.9.1: The laryngograph electrodes. Source: Fourcin (1974(a):317).

larynx to enable the measuring of the varying electrical impedance across the glottis without any inconvenience to the speaker and without disturbance to phonation. The flow of the current will be at its maximum when the vocal folds are maximally in contact, and at a minimum when the folds are apart. This point is basic to a proper understanding of the laryngograph and subsequent Lx (Larynx excitation) waveform interpretation.

### 5.9.1.2 The Lx Waveform and Quantification of Results.

During voiced sounds the vocal folds vibrate and this results in quasi-periodic Lx waveforms as the folds close and open many times a second. The vocal fold's vibratory details can be related directly to the Lx waveform cycles in a regular voiced sound. Fig. 5.9.2. gives the basis for describing the Lx waveform cycle in more detail.

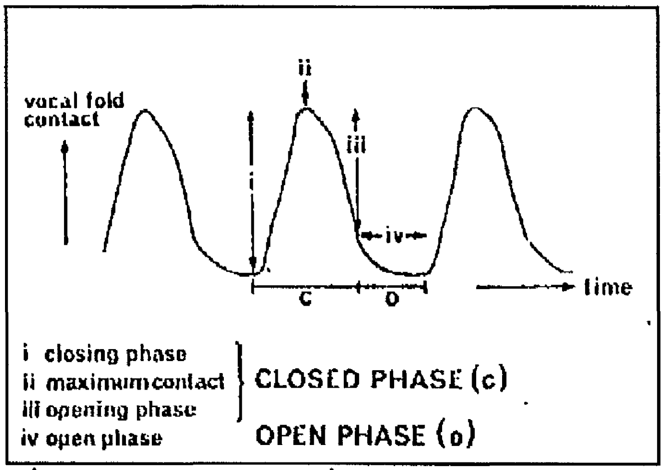



Figure 5.9.2: Typical Lx waveform (modal voice).
Source: Abberton et al. (1989).

It can be observed that the figure consists of four main features namely:

i a steeply rising edge followed by
ii a maximum peak, then
iii a shallow falling edge and
iv a trough essentially unchanged with time.

These correspond to the vocal fold:

i    closing phase
ii   maximum closure
iii  opening phase and
iv   open phase          (cf. Abberton et al. 1989:4).

The relative lengths of these phases can change with voice quality (cf. Section 5.9.4 below for detailed discussion). The phases (i-iii) are often referred to collectively as the "closed phase" since the folds are in some degree of contact from the start of the closing phase (i) to the end of the opening phase (iii) as against the open phase (iv) (cf. Abberton et al (1989:4)). Measures which are proving useful are the lengths of the open phase (iv) and closed phase (i- iii) (cf. Lindsey et al 1986), and these are often expressed as a ratio (cf. below).

Open and closed phases have been defined in various ways by different authors. Hirano (1981) uses these labels with his glottal area function in a slightly different way, and this may cause confusion if one is not clear with the terminology employed. This function rises from zero to a peak as the folds fully separate (Hirano labels this "opening phase"), and it falls back to zero as they come together to the point where their bottom edges meet (Hirano labels this "closing phase"). This portion of the glottal area function (the rise together with the fall) is equivalent to the open phase (iv) on the Lx waveform, and Hirano also labels this portion as the "open phase". The glottal area function remains at zero during the remainder of the cycle (Hirano labels this "closed phase"), whilst the Lx waveform rises to its peak and falls (i-iii) for its closed phase. Thus the labels "closed phase" and "open phase" coincide for the glottal area function and Lx waveform, but care must be taken with the labels: "opening phase" and closing phase" (cf. Howard et al. (pers. comm)).

Reinsch and Gobsch (1972) also assumed the vocal folds to be closed at the top of the laryngogram (in their terminology, glottogram). The assumption was based on the correspondence of the top to be the smallest value of impedance. This again corresponds to Fourcin's closed vocal fold phase (ii). They define the steep slope (phase i) as the closing of the vocal folds and the flat slope (phase iii and iv) as the opening and the open condition of the vocal folds. To avoid confusion that might arise from different descriptions, I have adopted Fourcin's descriptions.

One useful measure which can be derived from laryngograms (or glottograms) is the cycle-by-cycle open quotient (OQ) of voiced portions of speech. The OQ is defined as, the percentage of each period during which the glottis is estimated to be open. The algorithm used in this study defines the upper 70% of the peak-to-trough amplitude of each Lx cycle as representing closure, and the lower 30% as glottal opening. Values were obtained by means of a specially designed computer program (see Davies et al 1986 for further discussion and other algorithms).

### 5.9.2 Advantages and Disadvantages of the Technique.

The technique has the following advantages: (cf. Abberton and Fourcin (1984), Abberton et al. (1989), Fourcin (1974a, 1981 and 1986), Fourcin and Abberton (1971, 1976), Howard (1988 and 1989), Howard et al. (pers. comm) and Lindsey et al. (1986).

1 The arrangement of the technique is quite straight forward and easy to use.

2 The superficially applied electrodes allow the monitoring of the activity of the vocal folds with minimum discomfort to the subject as the technique is not invasive.

3 If the electrodes are placed properly there is relatively little variability of the laryngograph output for a given speaker.

4 The technique has an added advantage of not being affected by acoustic interference from the neighbourhood. Its displays should therefore be correct and undistorted.

5 Unlike other methods, the technique can be used with a wide variety of subjects (thin or fat necked subjects or even babies).

6 The period of each laryngeal cycle can be measured and pulse recurrence rate or fundamental frequency calculated in a very simple and reliable way from the clear indication of the timing of vocal fold contact.

7 The presence or absence of glottal vibrations can easily be determined from the graphic display.

8 Clinically, laryngographic measurements make it possible to detect pathological changes that may not easily be detected through audio signal analysis where only an average value for each laryngeal period is computed. With the laryngograph any abnormality of the vocal folds is likely to interfere with the detailed Lx waveform shapes and Fx curves. For example, in a patient with unilateral paralysis or polyp, the vocal folds vibratory system will generate an Lx waveform which as a consequence of this disability shows some irregularity of closure and excitation (cf. Abberton (1976), Fourcin and Abberton (1976), Neil et al. (1977), also section 5.9.6).

9 Simultaneous recording of speech and Lx can be done on a two track tape recorder. Either the speech can be listened to or the Lx alone can be played back from the other track. This is a useful way of keeping a permanent record of the laryngograph output for analysis.

With all these advantages, however, there are some problems associated with using the laryngograph:

1 It is not possible to determine whether the vocal folds are coming into contact throughout their length or whether there is a glottal chink at the arytenoid end of the glottis. Hence, it is difficult to decide on the degree of glottal constriction.

2 The electrical current distribution within the vocal folds may not be constant from speaker to speaker. If speakers have thick skin or a very fat neck, this may cause interference in the amount of current flow through the device producing a very small signal, sometimes hardly enough to be detected.

3 The movement of the larynx up and down could cause variation in the Lx waveform as this may interfere with the amount of current flow.

5.9.3 Comparisons with other Techniques.

Investigating phonation types (the types are not meant to be contrastive in any language) Fourcin (1974a) uses the laryngographic technique in conjunction with audio recording and a stroboscope (cf.5.3.3). Four subjects phonating a sustained vowel /a/ were used in the investigation. Fourcin described the Lx waveforms of these different phonation types in terms of their general characteristics in speech production. The phonation types examined are:

1 modal (normal) voice
2 breathy voice
3 creaky voice and
4 falsetto.

To establish the usefulness of the electrolaryngograph, measurements were taken from the original stroboscopic pictures of the changes in laryngeal structures while the subject was phonating a sustained breathy vowel /a/. The parameter glottal area was measured and results presented graphically. The Lx waveforms for the above mentioned phonation types and the corresponding stroboscopic pictures were compared. Observation of the results confirmed the graphic evidence that there was an antiphase relation between the output of the electrolaryngograph on the one hand and the degree of glottal opening indicated by stroboscopic pictures on the other. See representative waveforms and stroboscopic pictures showing vocal fold movement during phonation shown in Fig. 5.9.3 (a and b). All the pictures were analyzed in the sequence demonstrated by the electrolaryngograph display.

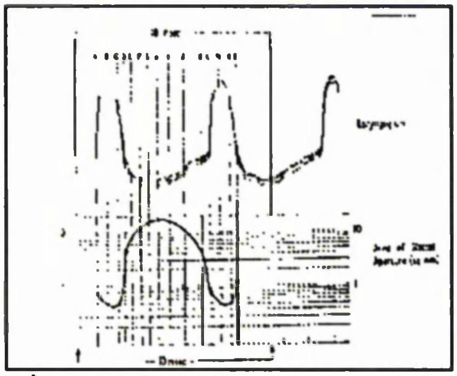


Figure 5.9.3:
(a) Comparison of laryngograph output with the glottal area and (b) simultaneous photographed stroboscopic pictures. Source: Fourcin (1974(a):318-319).

Figure 5.9.3(b)

In order to test the usefulness of the electroglottograph Lecluse et al. (1975) tested several models in collaboration with a stroboscope (cf. Section 5.3) to see whether they can actually monitor the motion pattern of the vocal folds. In this study, the authors confirmed that in general the vocal folds are closed in the area of the top of the Lx curve and open in the area of the bottom of the curve (cf. Fig. 5.9.4). Their purpose was to examine performance of various European electroglottographs, not including Fourcin's laryngograph. The different models of the electroglottographs were:

1 EG-1 The Loebell electroglottograph MG 8 -built by Martin Gruber; Munich.

2 EG-2 Electroglottometre Mark IV - built by van Michel; Liege.

3 EG-3 A modified version of EG-2.

4 EG-4 The EG 830 EGG constructed by Frokjaer Jensen; Denmark.

5 EG-5 and EG-6 Glottographs built in the Department of Oto-rhino-laryngology, Eramus University; Rotterdam (cf. Lecluse et al. 1975:216-217).

The EGGs were first tested on excised human larynges, and on a number of subjects phonating the Dutch vowels- /a/=[a], /i/=[I], /oe/= [u], /o/=[O], and /u/=[y]. In this study glottal activity was measured for various positions of the electrodes (on the neck against the thyroid cartilage) with the aim of finding the position of the electrodes that produced maximum signals (cf. Fig. 5.9.4 and Fig. 5.9.5). The authors compared specific instants of the glottogram, with the stroboscopic pictures of the vocal folds (cf. Fig. 5.9.4). Their observations were as follows:

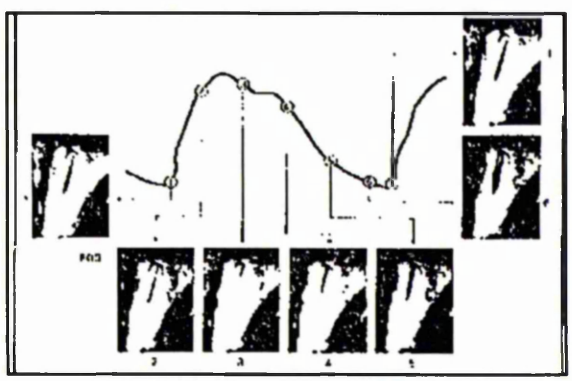


Figure 5.9.4: Electroglottographic signal and stroboscopic pictures of the vocal folds. The phase of the stroboscope is numbered in the glottographic signal to illustrate the relation between glottogram and stroboscopic pictures. Source: Lecluse et al (1975:219).

1 Although a good relation between the glottograms and the stroboscopic pictures was observed, the larynx waveforms cannot be correlated with physical events as generally or as simply as the labels "closing, closure, opening and open" imply. According to Lecluse et al. (1975)

"The area of contact (of the approximating vocal folds) moves as a result of the Bernoulli effect. During this upward motion the glottogram does not show a flat top, but a further building of a top and a beginning of the decrease. This may be caused by variation of the size of the area of contact. In return, this variation will make it impossible to define the moment of total closure as the top of the curve. Also the definition of the total opening of the vocal folds is impossible" (Lecluse et al. 1975:222-23).

Nevertheless, Lecluse et al. confirm in general that the vocal folds are closed in the area of the top of the glottogram curve, and open in the area of the bottom of the curve (cf Fig. 5.9.4).

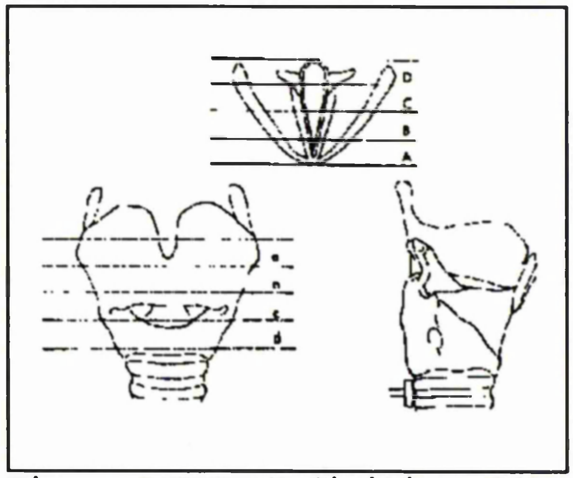


Figure 5.9.5: Definition of the areas for obtaining a glottographic signal. Source: Lecluse et al (1975:218).

2 The amplitude of the signals was found to vary according to the positions of the electrodes on the larynx - maximum at the level of the vocal folds, and lower in other positions. Different models of the EGGs give different results. See Fig. 5.9.6 which gives signal classifications for the different glottograms at various positions.

3 The glottograms for the various vowels studied also differ from each other. See Fig. 5.9.7 which gives the glottograms of a normal subject, producing some vowels. It can be seen that EGG 830 produces almost identical signals for all vowels while MG 8 produces

Figure 5.9.6: Signal classification for different glottograms at various positions near the larynx. Source: Lecluse et al. (1975:218).

| | A | B | C | D | a | b | c | d | Other positions |
|---|---|---|---|---|---|---|---|---|---|
| EG-1 (MG 8) | ± | + | + | ++ | ++ | + | + | - | ++ |
| EG-5 (design MG 8) | ± | + | + | ++ | ++ | + | + | - | ++ |
| EG-2 (Mark IV-a) | + | + | ± | - | - | + | ± | - | - |
| EG-3 (Mark IV-b) | + | + | ± | - | - | + | ± | - | - |
| EG-6 (design Mark IV) | + | + | ± | - | - | + | ± | - | - |
| EG-4 (Frokjaer J) | ++ | ++ | + | - | - | ++ | + | - | - |

Signal-to-noise ratio:
++ very good >40dB; + good ≈40dB;
± medium between 30 and 40dB; - bad ≈30dB.

different signals for each vowel. The other models produced similar results to the MG8.

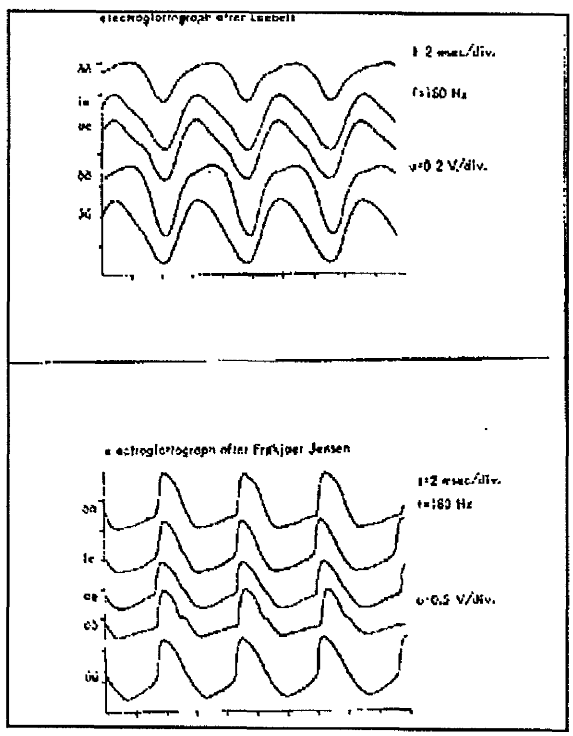


Figure 5.9.7:
(A) The glottogram of a normal subject pronouncing the vowels /a/, /1/, /u/, /O/, and /y/. The results obtained by the MG-8.
(B) The glottogram of a normal subject pronouncing the vowels /a/, /i/, /u/, /O/, and /y/. The results obtained by the EG-830. Note the differences in shape of the glottograms by the MG-8 and the similarity in the glottograms by the EG-830.
Source: Lecluse et al (1975:220).

The fact that there are variations in the results obtained between the various models of the electroglottographs made Lecluse et al. doubt the usefulness of the technique.

However, discussing the results from an electrical point of view, they suggested that variation in the results could be due in part to the different models of the EGGs or due to variation of the capacitance caused by the vibrations of the laryngeal wall, or the skin of the throat.

Figure 5.9.8: Idealized vocal fold contact area (VFCA) waveform during normal, non-breathy voicing and its relation to the glottal air flow pulse. After Rothenberg (1981:92).

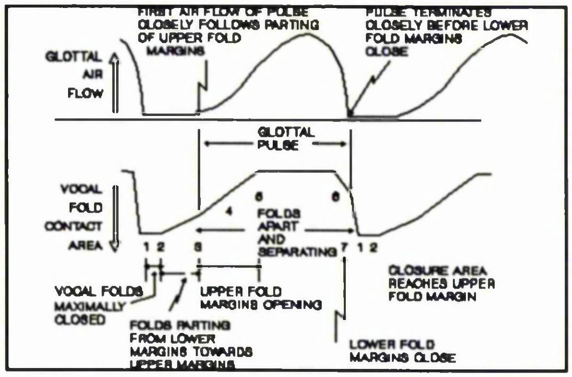
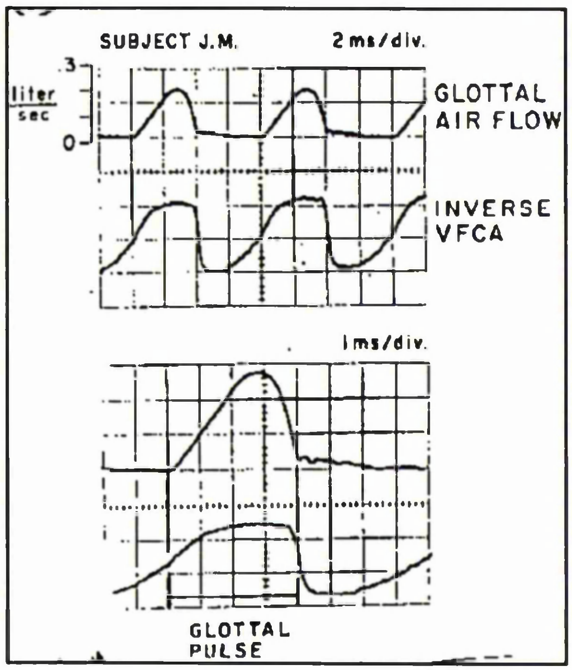



Figure 5.9.9: Glottal air flow and vocal fold contact area during /ae/ in the syllable /bae/. Source: Rothenberg (1981:92).




Rothenberg (1981) examined the correlation between glottal air flow and vocal fold contact area by means of an Inverse filtering technique in conjunction with the electrolaryngograph (cf. Fig. 5.9.9 and also section 5.11.3). On the basis of the laryngographic recordings, he proposed a seven-stage model for the vocal fold contact area waveform in voiced speech. It should be noted that the waveform given here is not quite the same as Fourcin's definition of the various parts of Lx. Rothenberg suggested a physiological interpretation that relates to these stages (here only four stages will be discussed, see Fig. 5.9.8 for the others).

Rothenberg reported that:

1 During the closed portion of the glottal cycle 1 to 3 the laryngograph waveform shows a relatively flat portion, 1-2, initiating the closed phase during which the vocal folds are being compressed without much change in contact area (cf. Fig. 5.9.8). However, during 2-3, the waveform rises continuously. Rothenberg suggested that this rise corresponding to decreasing inverse vocal fold contact area during the closed portion of the glottal cycle, may be associated with the slow separation of the lower margins of the vocal folds as they roll from below.

2 At 3, the glottal airflow begins to rise, indicating that the vocal folds have begun to separate.

3 During the upper margins of the inverse vocal fold contact area waveform 5-6, it is assumed that the vocal folds are fully apart.

4 The termination of the glottal pulse, which is accompanied by the onset of a sharp drop in the inverse vocal fold contact area waveform at 7 is suggested to be due to the coming together of the vocal folds into contact (cf. Fig. 5.9.8).

Rothenberg concluded that,

> "the accurate inverse-filtering of oral pressure or flow requires an approximate identification of the interval of glottal closure. We have found

> that the vocal fold contact area be very helpful in this regard and can extend the inverse filtering procedure to much larger range of voice qualities, Fo values, and vowel types" (Rothenberg 1981:94).

Childers, Smith and Moore (1984) tested the usefulness of the electroglottographic technique by comparing it with other techniques in laryngeal assessment. They demonstrated the validity of the EGG in conjunction with ultra high speed photography (cf. section 5.4.3) in monitoring normal and pathological vocal folds. They aimed at establishing a definite correspondence between the vocal fold contact, glottal area, the EGG waveform, and the acoustic signals.

A total of eleven adult subjects with normal laryngeal conditions (8 male and 3 female) were recorded. The subjects phonated the vowel /i/, sustained for about 3sec, at a constant pitch. For comparison purposes the sampled speech and EGG waveforms were aligned and compensation was made for the acoustic propagation delay of the speech waveform relative to the EGG signal. For analysis of the ultra high speed picture, a grid was placed in the focal plane of the vocal folds which allows a good measure of vocal fold displacement and glottal area. The authors describe the system as follows:

> "The vocal fold was measured from the ultra-high-speed laryngeal films using an image processing system which projected a film frame via a television camera on to a high quality gray level computer image terminal. This terminal has graphics overlay capability as well as a joystick cursor which can be moved under operator control.The position of the cursor is read by the computer" (Childers, Smith and Moore (1984:107).

They studied the degree of vocal fold contact along the midsagittal line as well as the glottal area. The measure of the vocal fold contact was calculated as a

> "ratio of the length of the vocal folds in contact along the midsagittal line in a given laryngeal film frame to the maximum length of contact along the midsagittal line for the complete set of film frames for a given task" (Childers, Smith and Moore 1984:107).

Considering the two-dimensionality of the film data, the authors consider this measure to be a correlate of the lateral vocal fold contact area. The vocal fold contact and glottal area are depicted on the graphs in the following manner, "glottal closure or increasing vocal fold contact is a downward deflection in the respective waveform, and the EGG waveform varies similarly, with the waveform minimum corresponding to closure and the maximum corresponding to opening" (Childers, Smith and Moore 1984:107)

The waveforms discussed here are "upside-down" from the point of view of Lx (cf. Fig.5.9.10). Thus maximum of waveform coincides with maximum glottal opening. In the Lx waveforms maximum of waveform coincides with maximum closure). See Fig. 5.9.11 which shows a synchronized speech, EGG, and area waveforms.

The various parts of their EGG signal are as follows:

1 The rising portion of the EGG waveform corresponds to the glottal opening phase.

2 The maximum of the EGG waveform coincides with the maximum glottal opening.

3 The declining portion of the EGG waveform corresponds to the closing phase.

4 The "knee" or "break" in the negative slope of the EGG waveform corresponds to initial vocal fold contact along a margin during the closing phase, and

5 Glottal closure or the point of minimum glottal area coincides with the minimum of the EGG waveform.

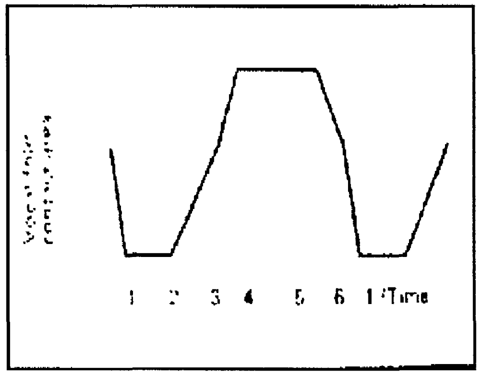


Figure 5.9.10: Idealized modal of vocal fold contact area. 1-2, vocal folds maximally closed; complete closure may not be obtained; flat portion idealized. 2-3, folds parting, usually from lower margins toward upper margins;3, when this point is present, this usually corresponds to folds opening along upper margin. 3-4, upper fold margins continue to open. 4-5, folds apart, no lateral contact; idealized. 3-6, open phase. 5-6, folds closing. 6, fold closure occurs along lower or central margin; complete closure may not occur. 6- 1, rapid increase in vocal fold contact area.
Source: Childers et al (1984:116).

Childers, Smith and Moore made the following observations in normal vocal conditions.

1 Vocal fold contact increases upward towards the upper margin as the folds roll upward.

2 Contact increases simultaneously along the midsagittal plane as glottal closure occurs. In other words, vocal fold contact is increasing simultaneously vertically and sagitally.

3 Considerable variations between the subjects also occur.

On the whole, Childers, Smith and Moore considered that their data clearly demonstrated a close relationship between the EGG signal and the nature of the activity going on at the glottis. Hence they conclude that the technique is effective in speech research.

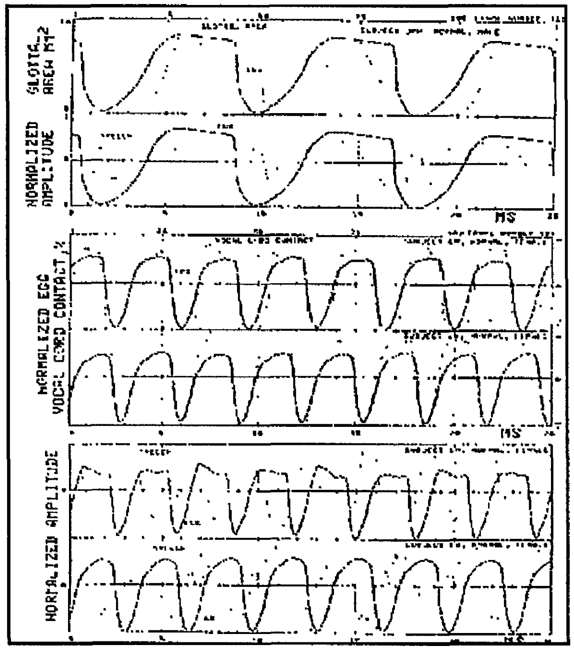
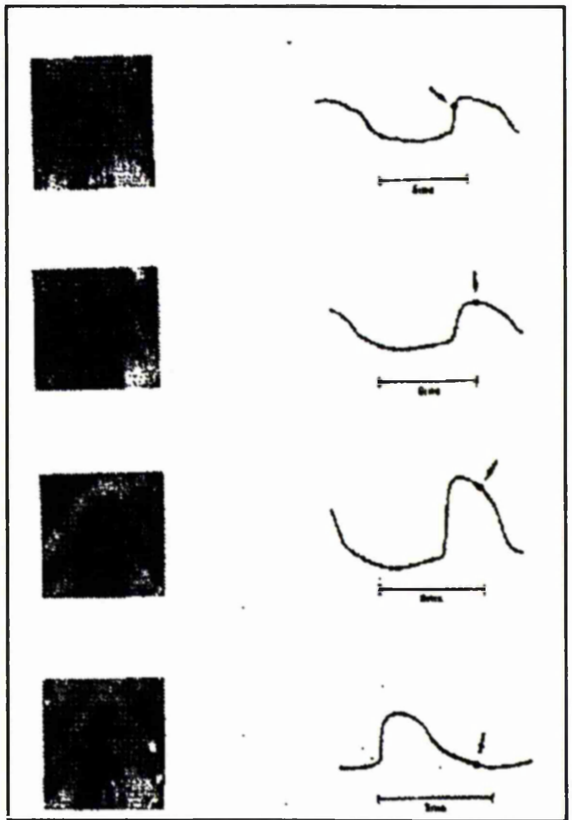


Figure 5.9.11:
(A) synchronized speech, EGG and glottal area waveforms for normal male subject (upper two graphs); (B) synchronized glottal contact and EGG waveforms for normal female subjects (middle two graphs); and (C) synchronized speech and EGG waveforms for normal female subjects (lower two graphs). EGG is always shown as the solid line. Source: Childers et al (1984:109).

In a study which sought to establish the usefulness of the electrolaryngograph as a technique for monitoring vibratory pattern of the vocal folds, Noscoe et al (1983) have correlated X-ray radiograms of the vibrating vocal folds with the output of the electrolaryngograph (cf. section 5.6.3 for experimental procedures and X-ray study). In the investigation, the electrolaryngographic display of the subject's own phonation was used to trigger individual 30 nanosecond X-ray pulses to produce a series of images of the full range of the vocal fold movement in normal phonation. Fig. 5.6.2 shows a Lx waveform indicating the four predetermined points and four representative X-ray radiograms showing the cycle of vocal fold movement during phonation. All the X-ray radiograms were analyzed with the sequence of events identified from the Lx waveform (cf. section 5.6.4 for parameters measured). The authors found that a great correlation exists between the characteristics of the electrolaryngograph waveform and the observable vibratory behaviour of the vocal folds as seen on the X-ray radiograms.

More recently Fourcin (1986) has correlated flash X-ray radiographic views of the vibrating vocal folds with the output of the laryngograph. He confirmed that increased vocal contact results in positive going Lx waveform changes. The X-ray (cf. section 5.6.4) flash source was synchronized with the laryngograph waveform, so that any pre-determined instant in the Lx waveform could be used to trigger an instantaneous frontal illumination of the speaker's vocal folds. In this way the vocal folds were photographed in their phonatory movements. Fourcin presents four pictures of the vocal folds corresponding to four positions on the Lx waveform (cf. Fig. 5.9.12) as follows.

Figure 5.9.12: Flash X-ray radiograms. Four separately recorded instants in the cycle of vibratory activity for a single adult male speaker are shown, together with the triggering instants on the associated waveform, Lx.
Source: Fourcin (1986:436).



The four specific points placed on the Lx waveform are:

1 Just before the peak of the Lx waveform is reached, and the X-ray imaging shows that the vocal folds are coming together, but just before closure.
2 At the peak of the Lx waveform; this corresponds to actual closure.

3 Just after the point of closure, a position on the Lx waveform which is typical for separation, and

4 On the flat base of the Lx waveform, an instant which shows that the vocal folds are apart.

Thus, there appears to be a high degree of correlation between the Lx waveforms and the radiographic films. Based on these results Fourcin argues that a close relationship exists between the characteristic pattern of the electrolaryngograph waveform and the observable vibratory behaviour of the vocal folds. According to him, this result firmly established the usefulness of the electrolaryngograph in laryngeal research (cf. Fourcin 1986:437).

5.9.4 Characterizing Phonation Types.

Fourcin (1974a) presents characteristic Lx waveforms for four phonation types: modal voice, breathy voice, creaky voice, and falsetto. These are shown in Fig. 5.9.13).

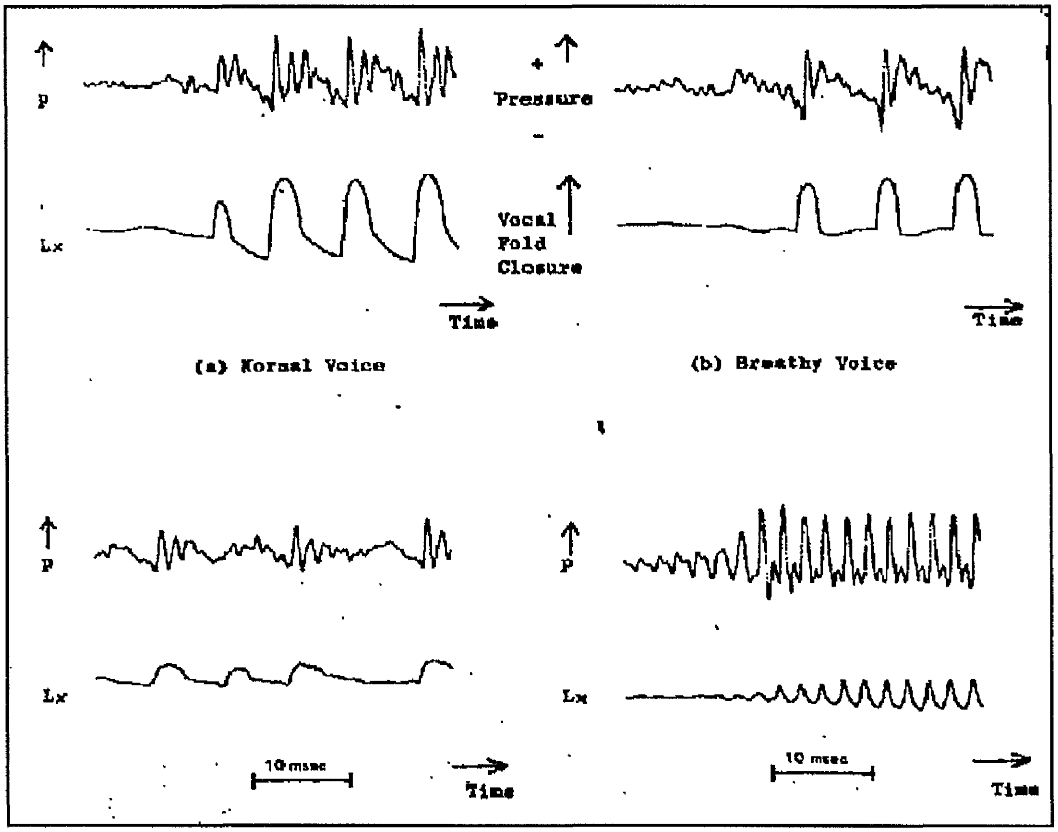



Figure 5.9.13 Speech pressure and Lx waveforms for various phonation types (speech waveform is always the upper and Lx the lower waveform). (a) Modal (normal) voice, (b) breathy voice, (c) creaky voice and (d) falsetto voice.
Source: Fourcin (1974(a):320).

As regards Lx waveform shapes and regularity, Fourcin states that for modal voice,

> "The closing and opening of the vocal folds occurs consistently, and the peak amplitude of Lx is soon stabilised. There is a relatively large closed-to- open phase ratio once phonation has begun, and the opening of the vocal folds is not as well defined as the onset of closure" (Fourcin 1974a:321).

As regards breathy voice,

> "Both opening and closing of the vocal folds are well defined, and the closed-to-open phase ratio is relatively small. The form of folds closure appears to be simpler than for chest voice: the vibration, once initiated, is as consistent" (Fourcin 1974a:321).

And for creaky voice,

> "The basic pattern of Lx for this voice quality indicates a long closure duration only moderately regularly repeated-and apparently with a small degree of closure-superimposed on which is a shorter period of vibration of variable occurrence. The onset of closure is always sharp and opening always slow" (Fourcin 1974a:321).

In falsetto voice,

> "The degree of closure is small, and closing and opening occur with equal rapidity. The shape of the Lx waveform is consistent with the time intervals for closing and opening being comparable with the total time of close contact" (Fourcin 1974a:321).

In a sociolinguistic study of voice quality in Edinburgh, Esling (1978) investigated different phonation types using the laryngograph in conjunction with a laryngoscope and correlated the Lx waveforms he obtained with the laryngoscopic pictures (cf. section 5.2.3). He examined Lx waveforms from his own speech and four other subjects who represented the four socially contrasting geographical areas of the city. The investigation was carried out in two stages. In order to compare settings of the glottis and the larynx in the contrasting social groups of the Edinburgh samples, the author (who was the only subject in the first experiment) observed his own larynx laryngoscopically while imitating voice qualities associated with the different social groups. He recorded the steady-state of the vowel

/i/ throughout and only phonation type was varied. The author chose this vowel because it corresponded to the most favourable tongue position for laryngoscopic filming, permitting an accurate comparison to be made between laryngographic results and the laryngoscopic description of the same phonation type (cf. section 5.2.3).

In the second experiment only the laryngograph was used. Four subjects (WF, SL, WRA and GAB) representing the four socially and geographically contrasting areas of the city were recorded. The subjects were all between the ages 54-64. They recorded the vowels /i/ and /e/. The steady- state of these vowels (during the [i] and [e] of "easy, seize, daisy, three and please") were used throughout and only phonation type was varied. For both experiments Lx waveforms were videotaped from an oscilloscope and used for analysis. Each of the phonation types was produced at least once in each of six separate sessions. The phonation types were: modal voice, whispery voice, extremely whispery voice, breathy voice, harsh voice, ventricular voice, creaky voice and falsetto.

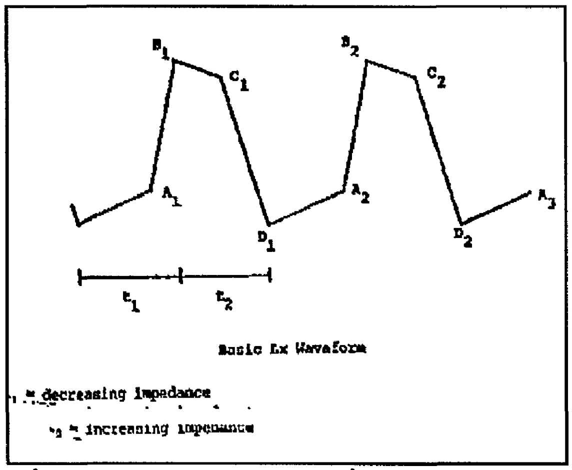


Figure 5.9.14: Basic waveform with four phases.
Source: Esling (1978:219).

Lx waveforms were examined in order to determine:

1 The characteristic pattern of the waveform shapes particulary with regard to decreasing and increasing impedance (cf. Fig. 5.9.14) and

2 The ratio of the durations of decreasing and increasing impedance. Decreasing impedance is the rising part of the trace, measured from the negative peak: and increasing impedance is the falling part of each trace, measured from the positive peak. Note that "decreasing impedance" and "increasing impedance" do not correspond to "closed phase"and "open phase" as defined above (cf. 5.9.1.2).

Esling reports the results of the second experiment as follows:

The duration ratio (the ratios are for the representative waveforms) in:

1 Creaky voice (at a frequency of 60Hz) has a deceasing-to-increasing impedance ratio of 0.53 or about 1 to 2. That is, Lx rises from the lowest point to the peak of the trace, representing decreasing impedance, in about half the time it takes to fall from the peak to bottom of the trace, representing increasing impedance.

2 Extremely whispery voice/breathy voice (at a frequency of 85Hz) has a decreasing-to-increasing impedance ratio of 9.66. This waveform has the highest impedance duration ratio of all the phonation types examined.

3 Harsh voice (at a frequency of 95Hz) has a decreasing-to-increasing impedance ratio of 0.61.

4 Ventricular voice (at a frequency of 100Hz) has a decreasing-to-increasing impedance of 0.35 This waveform has the lowest duration ratio of all the phonation types examined.

5 Whispery voice (at a frequency of 100Hz) has a decreasing-to-increasing impedance ratio of 2.50.

6 Falsetto (at a frequency of 305Hz) has a decreasing-to-increasing impedance ratio of 2.00 and

7 Modal voice (at a frequency of 125) has a decreasing-to-increasing impedance of 1.44.

See Fig. 5.9.15 which shows representative waveforms and the ratios of the representative waveforms and also Table 5.9.1 which shows the ranges of frequency and the mean ratio between the two phases for all tokens of each phonation type in order of increasing frequency of vibration. It can be seen that the ranges and the mean values of impedance duration ratio are reasonably distinctive from one phonation type to another. The ratios of the representative waveforms in Fig. 5.9.15 correspond, in their relative distribution, to the mean ratios in Table 5.9.1.

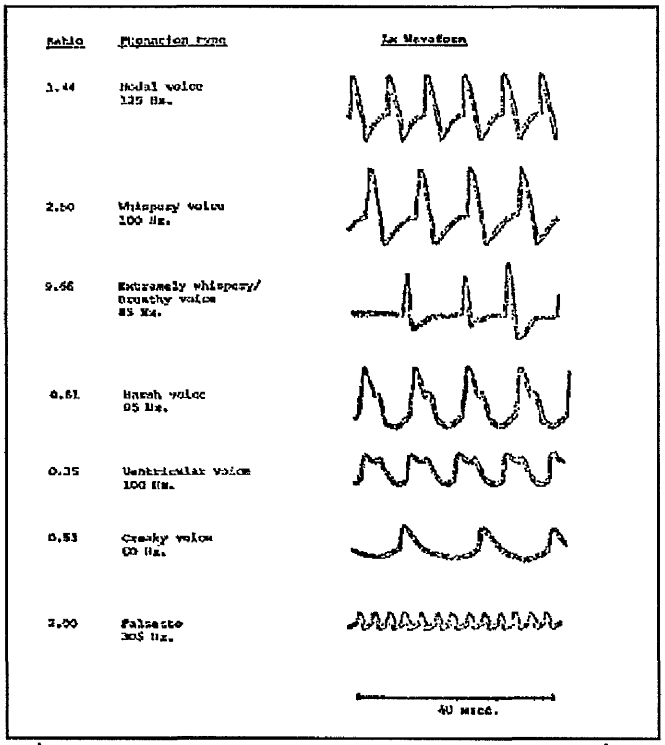



Figure 5.9.15: Representative waveforms and ratios.
Source: Esling (1978:226).

Table 5.9.1: Phonation types - Ratios.

| Phonation type (Number of tokens) | | Frequency range (Hz) | Duration ratio: decreasing to increasing impedance | |
|---|---|---|---|---|
| | | | range | mean |
| Creaky voice | (5) | 60 - 80 | 0.53 - 0.94 | 0.74 |
| Extremely whispery/ breathy voice | (4) | 75 - 100 | 0.60 - 10.00 | 8.06 |
| Harsh voice | (6) | 85 - 100 | 0.61 - 2.62 | 1.24 |
| Ventricular voice | (6) | 90 - 100 | 0.35 - 1.06 | 0.65 |
| Whispery voice | (7) | 85 - 140 | 1.16 - 3.14 | 2.33 |
| Modal voice | (6) | 100 - 130 | 1.16 - 1.62 | 1.34 |
| Falsetto | (6) | 275 - 345 | 1.66 - 3.50 | 2.49 |

With regard to the Lx waveform shapes, Esling reports that Lx waveforms for:

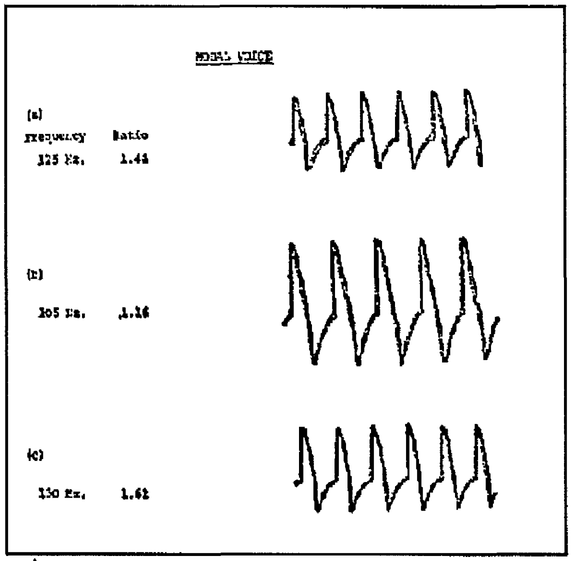


Figure 5.9.16: Lx waveform for modal voice at various frequencies.
Source: Esling (1978:229).

1 Lx waveform for modal voice has a phase of slowly decreasing impedance, a phase of rapidly decreasing impedance and a phase of increasing impedance. Duration of the decreasing impedance is only slightly longer than increasing impedance (cf. Fig. 5.9.16).

2 Whispery voice has a consistently longer phase of decreasing impedance than modal voice, decreasing begins relatively quickly, gradually slows down, and then abruptly reaches the positive peak. Impedance then increases steadily and fairly quickly to the negative peak. This Lx waveform shape suggests that there is greater glottal opening during whispery voice than modal voice (cf. Fig. 5.9.17).

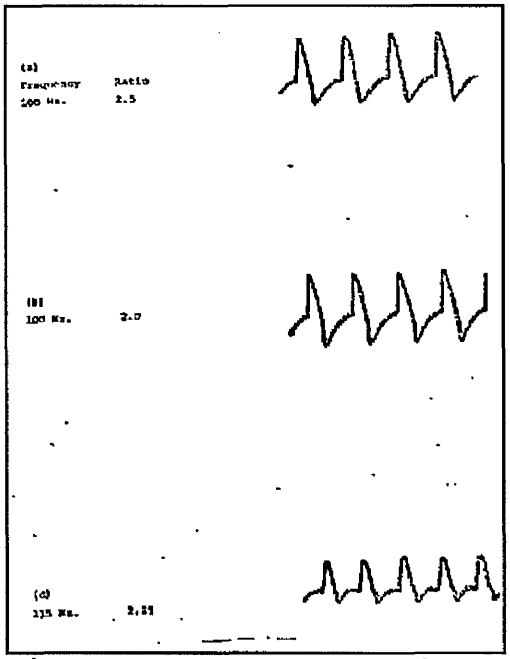


Figure 5.9.17: Lx waveforms for whispery voice at various frequencies. Source: Esling (1978:232).

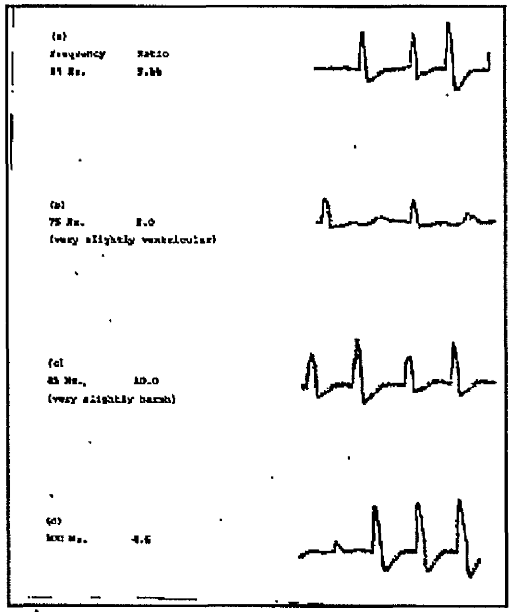


Figure 5.9.18: Lx waveforms for extremely whispery voice/breathy voice at various frequencies. Source: Esling (1978:236).

3 Extremely whispery voice/breathy voice have Lx waveforms which are distinguished by their long phases of relatively high impedance, with sharp (positive) peaks of minimum impedance. From the minimum, impedance increases immediately and very abruptly (cf. Fig. 5.9.18). This waveform suggests that the vocal folds are not in contact to as great a degree for this phonation type as for other types.

4 Harsh voice and Ventricular voice. The Lx waveforms for these phonation types were found to be similar. Both exhibit a periodically recurring arrest of the increasing impedance phase which ranges from 0.7 to 2.2msecs. for the six tokens of harsh voice and from 0.7 to 1.8msecs. for ventricular voice. The similarity between the two waveforms suggests that the difference between them is one of degree. However, ventricular voice may generally be distinguished from harsh voice by (1) a longer phase of increasing impedance and (2) a shorter phase of decreasing impedance preceded by a more abrupt transition across the negative peak. It may be suggested that in ventricular voice the vocal folds reach their maximum abduction more slowly but, once fully abducted, start to snap back together more quickly than harsh voice (cf. Fig. 5.9.19 and 5.9.20).

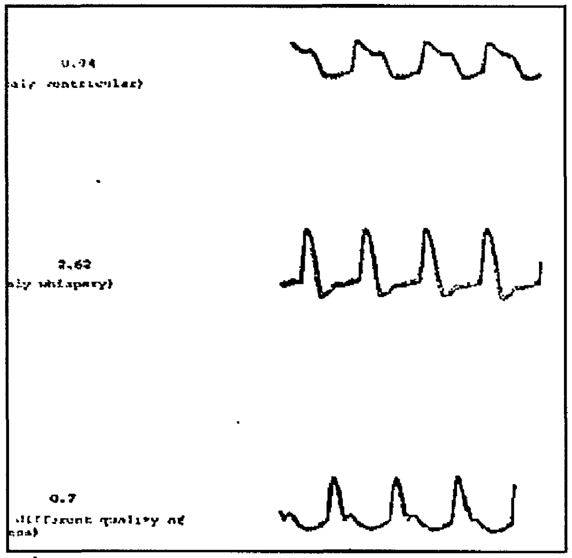


Figure 5.9.19: Lx waveforms for harsh voice at various frequencies.
Source: Esling (1978:240).

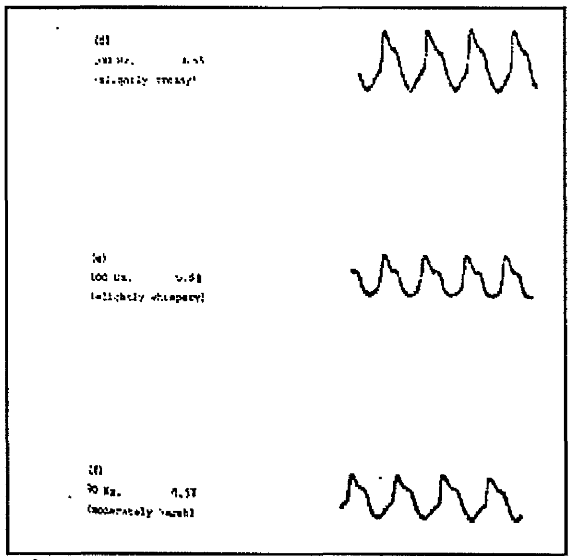


Figure 5.9.20: Lx waveforms for ventricular voice at various frequencies.
Source: Esling (1978:247).

5 For creaky voice the Lx waveforms show a relatively long phase of increasing impedance, and the beginning of the decrease is relatively slow. Glottal opening is least, as there is strong constriction at the glottis, while the vocal folds continue to vibrate in an increasingly irregular periodicity (cf. Fig. 5.9.21).

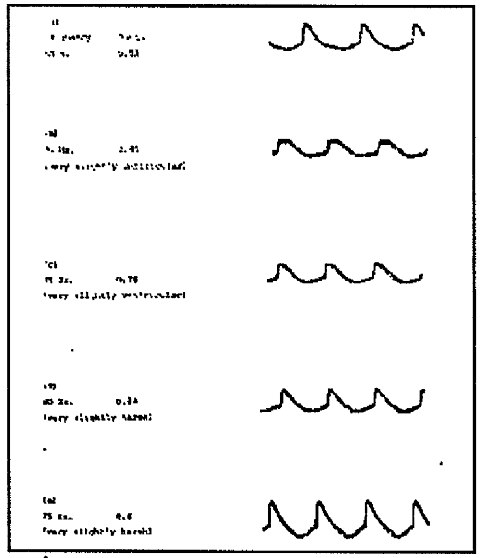


Figure 5.9.21: Lx waveforms for creaky voice at various frequencies. Source: Esling (1978:249).

6 Falsetto. The Lx waveforms show a uniformly high frequency with small amplitudes. In terms of impedance duration there is a relatively long phase of decreasing impedance (cf. Fig. 5.9.22).

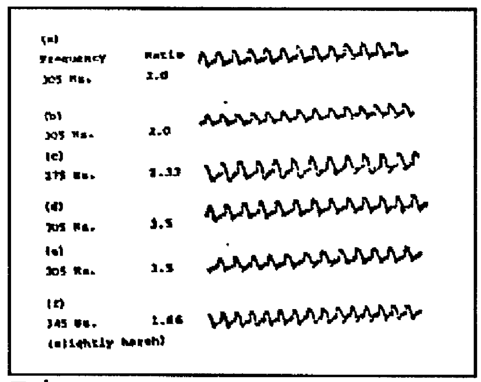


Figure 5.9.22: Lx waveforms for falsetto at various frequencies. Source: Esling (1978:252).

Esling applied the technique to the analysis of the Lx waveforms of some of the subjects from the Edinburgh samples as a means of providing an objective method of describing the sociolinguistic distribution of the phonation types in Edinburgh, Esling found that the results show a number of correspondences between auditorily identified differences in phonation type and laryngographic waveform shapes.

Measurement of the duration ratio of decreasing to increasing impedance shows that all speakers are similar. The mean duration ratio for WF is 0.86, SL 0.76, WRA 0.85 and GAB 0.82. In general, however, this criterion was found to be suitable in differentiating phonation types in a community where creaky voice and whispery voice or harshness and breathiness contrast.

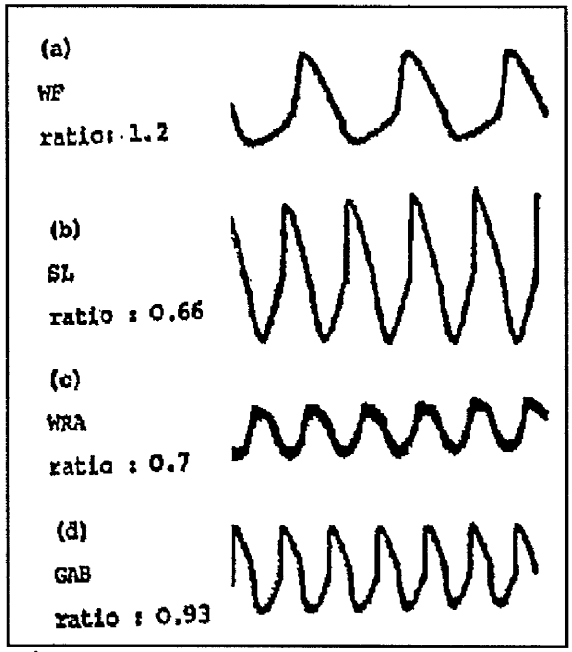



Figure 5.9.23: Lx waveforms of [i] of please for the four speakers representing the Edinburgh sample.
Source: Esling (1978:160).

As regards the Lx waveform shape, Esling notes that frequency and amplitude of the Lx signal vary considerably from speaker to speaker (cf. Fig. 5.9.23). Waveforms for WF and SL show relatively sharp positive peaks, whereas waveforms of WRA and GAB tend to have slightly flatter tops, indicative of momentary delay as impedance begins to increase. In respect to his study, Esling concludes that the laryngograph provides a more objective way for describing voice quality than generally believed to be possible.

### 5.9.5 Some Applications of the Technique in Speech Research.

With regard to linguistic investigations, the laryngograph has not been used very much for studying linguistically-significant phonation types. Lx characteristics of different phonation types have been defined largely for clinical purposes (cf. Section 5.9.6 below). However, there are a few studies that have used the technique.

A particular application of the laryngograph has been in the study of contrastive stop types in Korean (cf. section 5.5.3 for an explanation of the Korean stops). Investigating phonation during the production of Korean stops Abberton (1972) presents instrumental data using the laryngograph technique. She discusses the nature of the vibration of the vocal folds which follows release of the Korean stops. Laryngographic signals were recorded simultaneously with speech pressure waveforms. Two native speakers of Seoul dialect, a male and a female, acted as subjects. A comparison of the Lx waveforms obtained from the male speaker shows that the essential difference in voicing activity is between the aspirated stops and weak stops on the one hand, and the strong stops on the other. The strong stops show a characteristically different type of voice onset in both initial and intervocalic positions; usually between six and twelve cycles are needed before maximum glottal intensity is reached, whereas following the aspirated and the weak stops maximum amplitude is reached straight away or within two cycles (cf. Fig. 5.9.24).

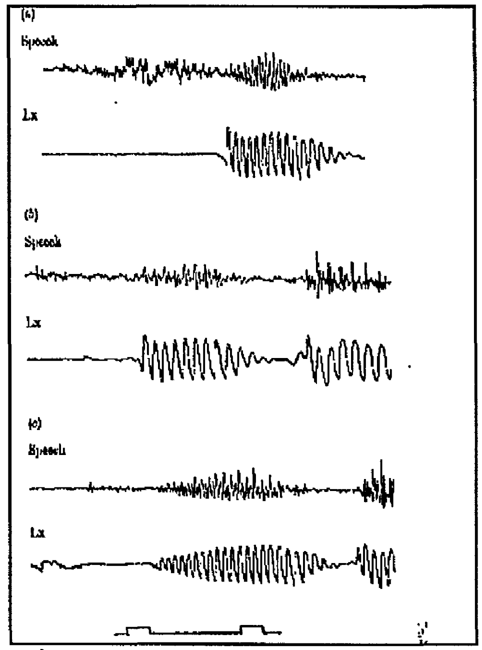


Figure 5.9.24: Speech pressure waveforms and Lx compared for three Korean utterances beginning with velars. Male speaker. (a) is taken from khida, (b) from kida, (c) from kkida. Period of the timing is 0.1 sec. Source: Abberton (1972:72).

As for the female speaker Abberton observed (although the recording was not always noise free) that after the strong stops, the gradual build-up of amplitude which characterized the speech of the male speaker was often not prominent, and for the other two types of stop (weak and aspirated), it was non-existent. Ladefoged (1983) has pointed out that different speakers of the same language may use different degrees of glottal activity to produce the same sound (in phonological terms). See also Lindsey (1986) and Lindau (1984). The data given by Abberton shows this variability between speakers.

In another study, Howard et al. (pers. comm.) have also described contrastive phonation types in Javanese using the electrolaryngograph. Javanese contrasts two series of stops, written b,d,g etc and p,t,k etc. Both series are voiceless but the first is produced with a lowered larynx and somewhat breathy phonation. Howard and his co-workers recorded several minimal pairs illustrating the distinction between these contrastive phonation types in different phonological environments.

Three adult Javanese speakers, two male and one female acted as subjects. Lx waveforms for vowels following the two types of stops were examined:

1 in terms of their general shapes, and
2 with regard to the length of the open phase.

Howard et al. note that one of the male speakers appeared to be replacing the voice quality distinction by a vowel quality distinction and there was no clear difference in the waveforms for the vowels following the two types of stops. In the case of the female speaker, there was a difference in the Lx waveform shape, both with regard to the general shape and with regard to the length of the open phase. The waveform for the vowels following the breathy series /b/, /d/, /g/ has a steeper downward slope than in the /p/, /t/, /k/ series. As regards the length of the open phase, the female speaker showed a relatively long open-to-closed phase ratio (cf. Fig. 5.9.25). Similar trends were observed in the Lx waveforms for the second male speaker as well.

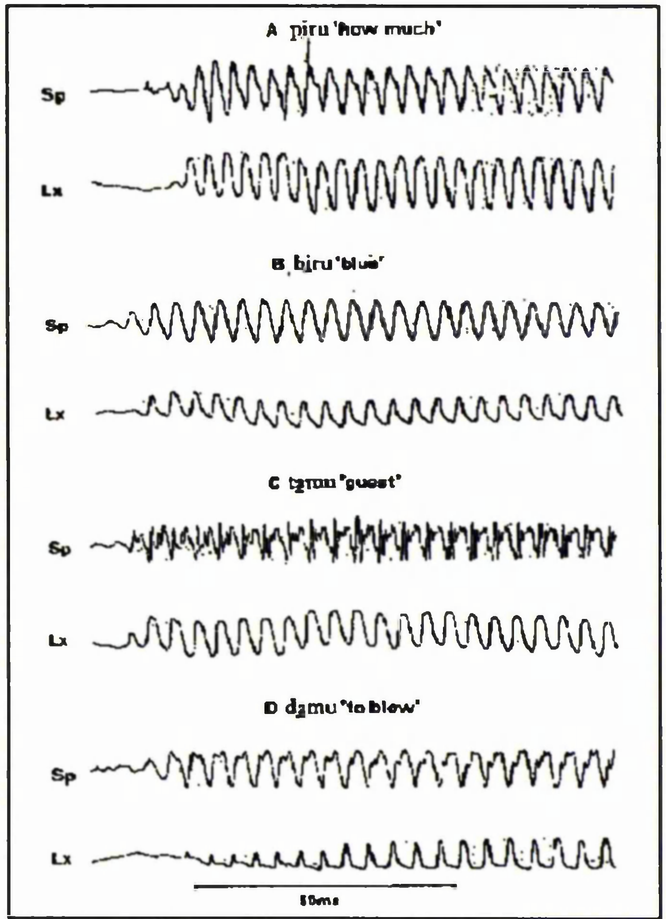



Figure 5.9.25: Sp and Lx waveforms for the vowels indicated spoken by a female Javanese speaker.
Source: Howard et al (Pers. Comm).

### 5.9.6 Clinical Investigations.

A full review of the literature on clinical application of the electrolaryngograph will not be given; I am going to consider only a few examples.

Unusual Lx waveforms have been demonstrated and discussed by Fourcin and Abberton (1971 & 1976), Fourcin et al. (1976), Abberton and Fourcin (1984), Parker (1974), Fourcin (1981), Wechsler (1976) and Carlson (1988). They describe the use of the laryngograph and voiscope (which includes the laryngograph) in speech therapy and present waveforms from several speakers with different types of vocal disorders. They looked at the Lx waveforms with regard to both its shape (related to the nature of vocal fold contact), and regularity of the vocal fold vibration.

Fourcin (1974a) hypothesised that, in a pathological situation, the Lx waveform would show characteristic features of certain vocal abnormalities. In other words, the simple periodic waveform of normal Lx (cf. section 5.9.1) will be absent in the disordered speech.

Abberton and Fourcin (1984) show Lx waveforms with corresponding speech pressure waveforms for different pathological conditions and for a normal speaker. They observed that the Lx waveform obtained from pathological cases shows characteristic features of certain vocal abnormalities. For example, the Lx trace may show random variation in the timing of vocal fold closure. With this type of Lx waveform, glottal closure is often not effected systematically and the degree of surface contact is irregular from closure to closure. It is sometimes possible for closures to be missed entirely (cf. Fig. 5.9.26).

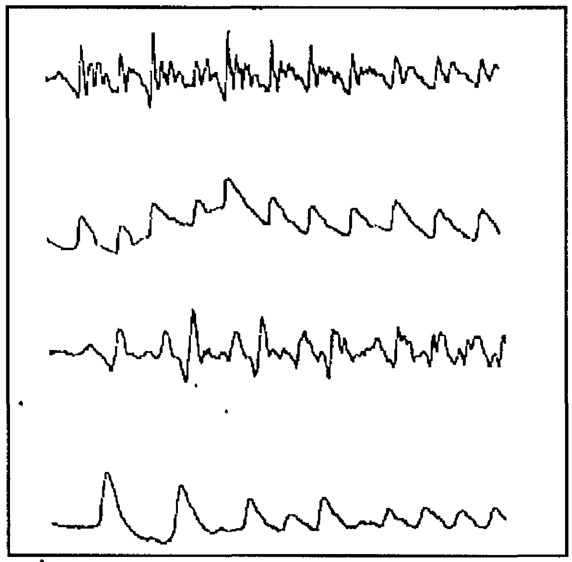


Figure 5.9.26: Abnormal waveforms obtained from a patient
(a-b) with laryngitis and
(c-d) with unilateral paralysis.
Source: Abberton and Fourcin (1984:70).

Abberton and Fourcin observed that the waveforms obtained from a patient with laryngitis (a and b) showed a Lx waveform which is very irregular from period to period. The shape of each closure peak differs from its neighbour, and the normally sharp vertical movement to closure is sometimes quite gradual - in which case it is associated with a corresponding small speech pressure peak. In addition, closure period is variable - the space between successive Lx peaks is erratic. The Lx traces obtained from a patient with a unilateral paralysis (c and d) showed considerable irregularity both of degree of closure (as shown by the heights of the Lx waveform peaks) and of period (Fig. 5.9.26). The shapes of individual closures are not markedly abnormal as the contacting fold surfaces are not themselves impaired. Vocal fold closure is 0.5 sec. duration for each sample (cf. Abberton and Fourcin 1984:70).

Another example of the application of the technique in therapy and clinical situations is Wechsler (1976). Wechsler, reports an investigation which looked at the vocal fold vibration before, during, and after treatment in twenty one patients suffering from several medically diagnosed disorders of the vocal folds. The most important factors he observed as regards the use of the Lx waveform in the study were Lx waveform shape and, in particular, regularity of vocal fold vibration. Waveforms were examined to see whether they were:

1 normal
2 regular in vibration or
3 of abnormal shape or had other abnormal features.

Comparing the Lx waveform types Wechsler notes a significant difference between the Lx waveforms obtained prior to treatment and after treatment. All the types of vocal disorders show a different kind of influence on the form of the Lx shape and regularity. See Fig. 5.9.27 and 5.9.28 which show Lx waveforms from a patient before and after treatment.

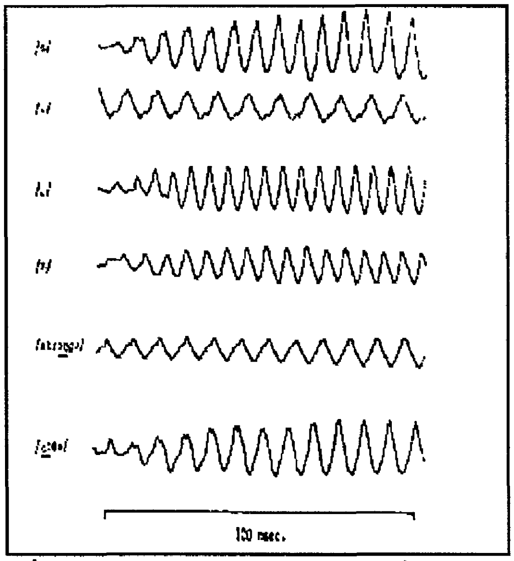


Figure 5.9.27: Lx traces pre-operative.
Source: Wechsler (1976:22).

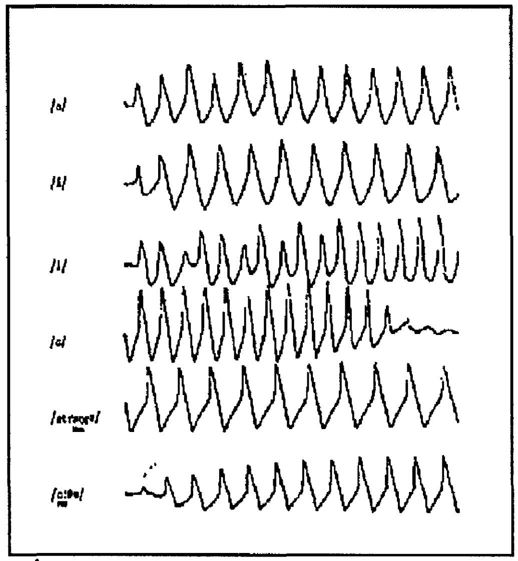


Figure 5.9.28: Lx Traces post-operative.
Source: Wechsler (1976:24).

The most noticeable feature in the Lx waveforms is the double peaking which occurs at greatest contact during vibratory onset. In Wechsler's view, this is probably due in part to an interference by a growth with the normal closure of the vocal folds.

After treatment, the previous abnormalities of the peaks have disappeared; a few of a different type can be seen in the peaks of the waveforms for /i/, but on the whole considerable improvement in regularity and Lx shapes can be seen.

Childers, Smith and Moore (1984) have used the laryngograph to monitor pathological vocal fold vibrations and report several case notes. They studied data obtained from synchronized ultra-high speed laryngeal films, EGG waveforms (cf. section 5.9.3 for EGG and details of how data was obtained) and acoustic recordings of speech (cf. 5.13.1). They report 11 cases of synchronized EGG and speech (/i/) recordings from individuals with abnormal voices. See Fig. 5.9.29 which presents examples of synchronized speech and EGG waveforms.

Some general relationships between the EGG waveforms and speech signals described above for normal subjects (cf. section 5.9.3) were considered. A comparison between the waveforms for normal voices and abnormal voices were then made. A visual examination of these waves led Childers, Smith, and Moore to conclude that the laryngograph signals revealed some abnormal vocal fold vibratory patterns (cf. Fig. 5.9.29). Analyses of the successive cycles of the Lx waveforms were performed for both normal and abnormal EGG. Some of the general relationships between the EGG signals and speech signals described above for normal subjects remain true for some of these abnormal voices. Periodicity analysis was carried out so as to discriminate laryngeal pathologies.

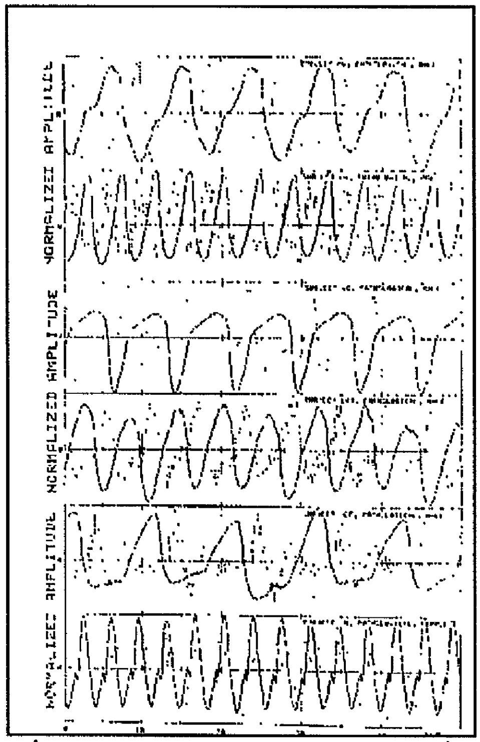


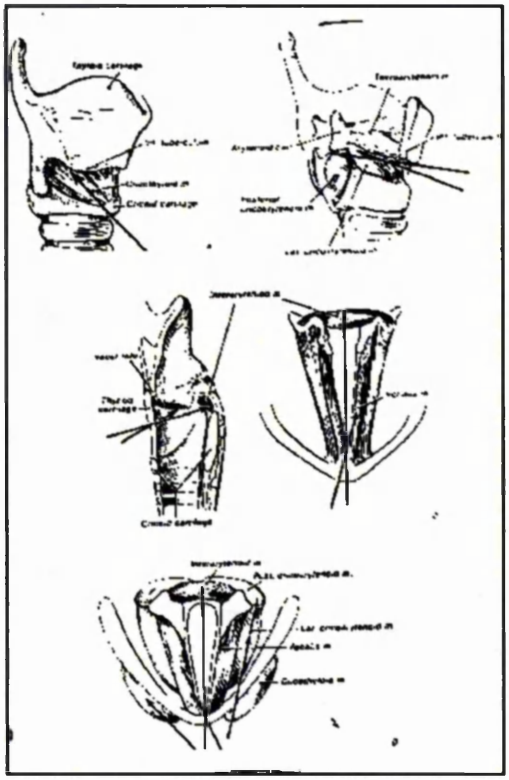
Figure 5.9.29: Synchronized speech and EGG waveforms for subjects with a vocal disorder. Source: Childers et al (1984:144)

A summary of their results for the pathological cases when compared with normal voices shows the following Lx waveform characteristics associated with pathological voices:

1 an unusual change in the rising slope of the EGG.
2 double periodicity in the EGG.

## 5.10 Electromyography.

### 5.10.1 Principles and Apparatus.



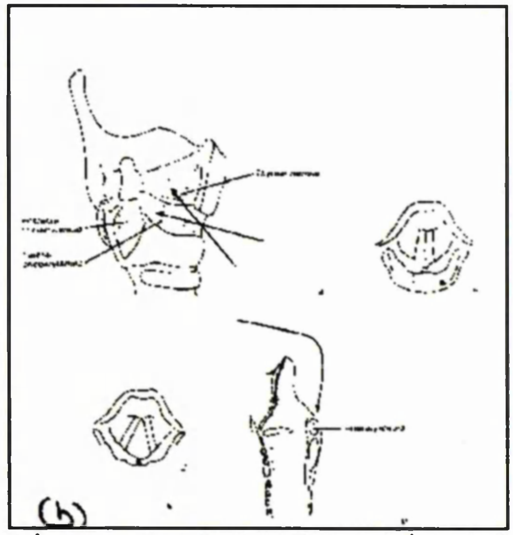


Figure 5.10.1: Insertion of the electrodes into the different laryngeal muscles.
Source: Hirano (1981:15).

Electromyography is a technique especially suited to the analysis of skilled movements in general, and of speech in particular. According to Cooper (1965:153), its particular advantage is that it provides direct information about the speech gesture in its natural unit.

In laryngeal research the technique has proved very useful in measuring the activity of the different intrinsic laryngeal muscles during phonation. This is done by recording the electrical discharge or action potential of the muscle fibres which make up a motor unit (cf. Cooper 1965). The signals accompany the muscle contraction which results in the movement of the articulators. Clinicians have also used the technique extensively in the examination of vocal fold disorders (cf. Sawashima et al. (1958), Hirose, Koboyashi, Okamura, Kurauchi, Iwamura, Ushijima and Sawashima (1967), and Hirano, Nozoe, Shin and Maeyama (1974)).

The electromyograph (the apparatus used to obtain an electromyogram, EMG for short) basically consists of an electrode system, an amplifier, a cathode-ray oscilloscope, a loudspeaker and a recording system. Two types of electrodes may be used:

1 needle electrode, or
2 hooked-wire electrode.

Faabong-Andersen's (1957) early work on electromyography of the laryngeal muscles used the needle electrode which he inserted through the mouth (cf. Faabong-Anderson (1957a and b)). This method has not been widely used, as the presence of the needle electrodes in the mouth and throat makes phonation difficult. Hirano and Ohala (1967 and 1969) developed the hooked-wire electrode technique which allows the insertion of the electrode into the intrinsic laryngeal muscles through the cervical skin. Hirano and Ohala (1967), Hirano (1969), Hirose (1971) and Hirano (1981:14-16) describe ways of inserting the electrodes into the different laryngeal muscles. The subject is usually seated in an examining chair or made to lie on his back with head tilted back. Anaesthesia is then carried out by spraying pharyngeal and laryngeal areas, and the electrodes are inserted. Correct placement of the electrode into the muscle is checked by monitoring with an oscilloscope while various manoeuvres take place. The electrode should be placed outside the muscle fibre membrane, to record the action potential of the muscles.

Since the muscle signals are very small, they are amplified and fed to a loudspeaker for auditory monitoring. In order to obtain a convenient quantitative record of the muscle activity, the raw EMG signal obtained from the several muscle fibres is then transformed into a display of amplitude versus time by the process of full-wave rectification and RC smoothing (integration). The envelope of the integrated curve gives an approximate indication of the strength of the muscle contraction (cf. Hirose 1971, Hirose and Gay 1972).

5.10.2 Advantages and Disadvantages of the Technique.

Advantages.

If the hooked-wire electrode is used by a skilled investigator the technique has the following advantages, according to Hirano and Ohala (1969:362) and Hirano (1981:12-13).

1 It offers minimum discomfort to the subject.

2 It does not interfere with normal phonation.

3 The electrodes stay in place fairly well regardless of the rapid movements of the vocal folds or the displacements of the entire larynx during phonation (but cf. point 3 below).

4 It permits considerable localization of the area from which electrical activity is recorded.

Disadvantages.

The technique has the following problems (cf. Hirano and Ohala (1967), Hirano (1969:362-4) and Hirano (1981:13)).

1 If the needle electrode is used, insertion of an electrode into the mouth and throat causes great discomfort to the subject and makes phonation very

difficult.

2 It is sometimes difficult to identify certain articulatory muscles.

3 The movement of the vocal folds or the entire larynx may sometimes make the signal obtained (electromyogram) unclear.

4 Although EMG is rather simple in concept it is extremely difficult in practice. The technique requires a skilled hand, and even then it is not always easy to insert the electrodes into the muscle(s) of interest.

### 5.10.3 Some Applications of the Technique in Speech Research.

Hirose and Gay (1972) examined the actions of the individual intrinsic muscles of the larynx during the production of the voiced/voiceless pairs /b/ and /p/, /z/ and /s/ and vowels in American English. The experiment aimed at determining the function of the laryngeal muscles in the articulation of the test segments in different phonological environments: initial, medial, final, prestressed and poststressed positions. They investigated the role played by the individual muscles (paying particular attention to PCA - posterior cricoarytenoid muscle, which is the abductor muscle) in the production of the segments, and studied the timing relationship between laryngeal and supralaryngeal muscle activity patterns. The other muscles investigated were interarytenoid (INT), vocalis (VOC), lateral cricoarytenoid (LCA) and cricothyroid muscles (CT); cf. Fig 5.10.1 above for the insertion of electrodes into these muscles. Results were plotted graphically.

Two adult male speakers of American English acted as subjects; for each subject, two separate test recordings were made, giving a total of four sets of data. The subjects read the list in random order sixteen times each. The EMG signals were recorded simultaneously with acoustic signals (cf. 5.13.1) and, using a digital computer, the integrated EMG signal at each electrode position was averaged. The averaged output was then converted into a display of amplitude versus time and plotted on a strip chart recorder. The envelope of the integrated curve was considered to indicate the strength of the muscle's contraction.

The variables measured were:

1 Level of muscle activity for the production of the various stop types,

2 Duration of the muscle's activity during the production of the segments, and

3 The timing relationship between the glottal gestures and the oral stop closure and release (VOT).

These three variables were then compared for each of the individual muscles. The results show that there is an interdependent relationship between the various muscles.

1 For the voiceless sounds /p/ and /s/ there is stimulation of PCA accompanied by suppression of INT whereas for the voiced sounds, there is continued suppression of PCA and excitation of INT. As far as the voiced/voiceless distinction is concerned, muscle activity in the laryngeal articulatory adjustment indicates a consistently greater PCA activity for voiceless consonant production than for voiced

consonant production regardless of phoneme environment.

2 As just noted INT shows a higher activity for voiced segments than for voiceless ones. However, INT activity for the production of vowels appears to be higher after voiceless consonants than after a voiced consonant.

3 VOC and LCA show a pattern of activity which is rather complex in laryngeal articulatory adjustments. The two muscles were found to be suppressed for consonantal segments irrespective of the voiced/voiceless distinction, while they appear to have higher activity during vowel articulation. This was particularly so for a stressed vowel rather than for an unstressed regardless of whether the stressed vowel is preceded or followed by the unstressed. This result made the authors suggest that VOC and LCA may participate in the control of suprasegmental features and possibly pitch raising. In this sense, the two muscles might be considered to function as tensors of the vocal folds (cf. Hirano, Vennard and Ohala (1970)).

4 The CT (activation of which increases the longitudinal tension of and stretches the vocal fold) shows a momentary increase in activity for a stressed vowel but without any appreciable difference with respect to the voiced/voiceless distinction.

5 In order to compare the timing relationship between the glottal gesture and oral stop release, three different points on the averaged PCA curve were measured with reference to implosion and release of the stop closure of medial voiceless stops. These points were: P1, the point where PCA activity began to increase for the stop production; P2, the point where

the activity reached its peak; and P3, the point where its activity decreased to its minimum for the production of the post-consonantal vowel.

The authors observed that the timing relationships between the laryngeal muscle activity and supraglottal articulatory events vary, depending on the phoneme environment. See Table 5.10.1 for a summary of their results. It can be seen for both subjects that the time intervals thus specified are always larger for poststressed stops than for prestressed stops. It is worth noting, in particular, that P3 always occurred earlier than the stop release for poststressed stops, while it never did so for prestressed stops. In other words, stop closure is released after complete suppression of PCA activity in the case of poststressed stops, while for prestressed stops, stop release occurs before the completion of PCA suppression.

Table 5.10.1: Time intervals for PCA activity in relation to stop closure and release in msec. A negative value in the third column indicates stop release preceding complete PCA suppression.

| | | Interval (in msec) between | | |
|---|---|---|---|---|
| | | P1 and stop closure | P2 and stop release | P3 and stop release |
| Subject 1 | | | | |
| /p/ | prestressed | 110 | 110 | -55 |
| | poststressed | 135 | 165 | 40 |
| Subject 2 | | | | |
| /p/ | prestressed | 110 | 60 | 90 |
| | poststressed | 150 | 130 | 10 |
| /t/ | prestressed | 70 | 45 | -140 |
| | poststressed | 160 | 95 | 0 |
| /k/ | prestressed | 85 | 40 | -165 |
| | poststressed | 155 | 140 | 30 |

Source: Hirose and Gay (1972:148).

In another study, Hirose, Lee, and Ushijima (1974) investigated the actions of the intrinsic laryngeal muscles in the production of Korean stops electromyographically. Korean has three stop types (cf. 5.5.3). One of the experimenters, who is a native speaker of Korean, served as the subject. He read randomized lists of test sentences 16 times each. In each sentence a test word was put in a frame. In the first part of the experiment, the test words were in the form of consonant plus vowel, the vowel being short and unstressed. The consonant was labial, dental or velar and the vowel was /i/, /a/ or /u/. About half of the consonant vowel /CV/ sequences were nonsense syllables but did not violate any phonological constraints of the dialect under investigation. In the second part of the experiment, the test words were in the form of /VCV/. EMG recordings were made using hooked-wire electrodes. The electrode insertion technique was as described in detail in Hirano and Ohala (1969), Cooper (1965) and Hirose, Gay, and Strome (1971).

The electrodes were inserted into four of the laryngeal muscles, INT, LCA, VOC, and CT. EMG signals were recorded on a multichannel data recorder simultaneously with acoustic signals and automatic time markers. The EMG signals from each electrode pair were averaged over more than 14 selected utterances of each of the test sentences with reference to a line-up on the time axis. The release of stop closure in each of the test words was used for the line-up. Separately from the EMG experiment, motion pictures of the glottis were taken using fibreoptics (cf. section 5.5.3).

The EMG curves of the different laryngeal muscles for the stop types were compared with each other in order to determine the pattern of their activity. The authors observed that there were differences in coordinated actions of the laryngeal muscles which characterized the different

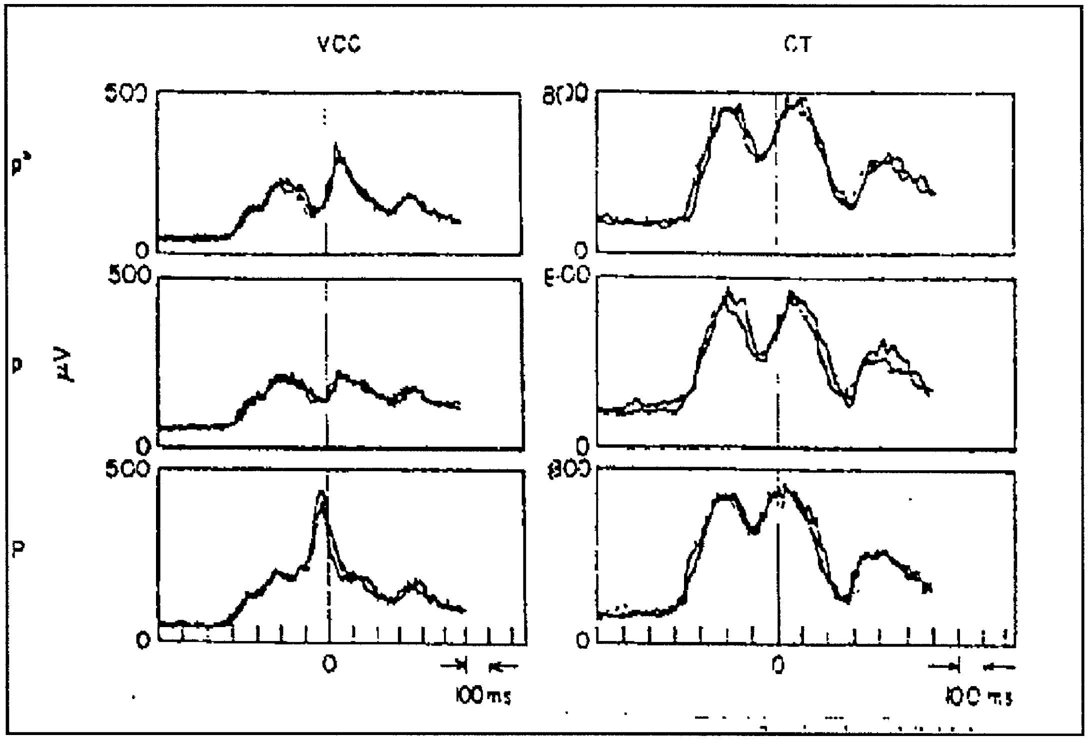
Korean stop types during their production. Their results are summarized as follows:

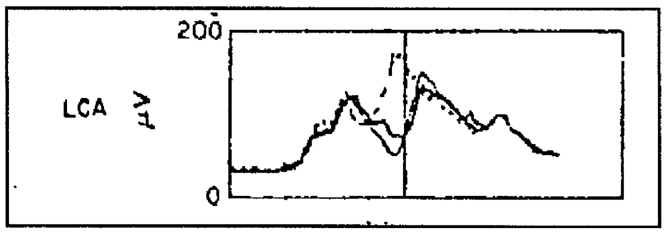
1 The aspirated stops were found to be characterized by suppression of all the adductor (INT, VOC, and LCA) muscles of the larynx immediately preceding the closure release. This is consistent with expectations, given the relatively large glottal width observed for these stops (cf. 5.5.3). The suppression was also found to be followed by a steep increase in activity which seemed to correspond to the rapid closure of the glottis after the stop release as observed by Kagaya (1971) (cf. 5.5.3).

2 For both the weak and strong stops in word-initial position, INT activity (usually considered to be reciprocal with PCA although this was not investigated here) was suppressed.

3 For all three stop types VOC and LCA show similar patterns of activity in that both show a marked increase of activity before the strong stop release regardless of the position of the consonant, while showing two separate peaks for both aspirated and weak stops. See Fig. 5.10.2 for VOC and Fig. 5.10.3 for LCA. The authors suggested that the increase of activity in the strong stop was probably due in part to an increase in the inner tension of the vocal folds as well as to the constriction of the glottis during or immediately after the articulatory closure (cf. Hirose, Lee and Ushijima 1974:151).

4 The pattern of CT activity is more or less constant for all the three stop types, being characterized by two peaks separated by a temporal suppression in the middle portion of the stop closure (cf. Fig. 5.10.2).




Figures 5.10.2 and 5.10.3. Averaged EMG curves of VOC and CT (Fig. 5.10.2) and LCA (Fig. 5.10.3) for the three bilabial stops in word-initial position. In each type, three curves are superimposed for the postconsonantal vowels /i/ and /u/ represented respectively by thin thick and dashed lines. The zero on the abscissa marks the line-up which corresponds to the release of the stop closure.

Source: Hirose, Lee and Ushijima (1974:148-149).

Kagaya and Hirose (1975) presented results of electromyographic investigation of the four types of Hindi stops (voiceless aspirated, voiceless unaspirated, voiced aspirated and voiced unaspirated), in conjunction with acoustic (cf. section 5.13.4.1) and fibreoptic (cf. section 5.5.3) investigation. EMG recordings were taken and the data were computer-processed to obtain the average activity pattern of the intrinsic laryngeal muscles as a function of time. The subject was a 44 year old male native speaker of

Hindi. He read the list of trisyllabic nonsense phrases /ThiKhiCi/ in isolation, where /C/ stands for one of the four types of labial stops /b/, /p/, /bh/, /ph/ or the dental /d/, /t/, /dh/, /th/ and the word-final vowel is stressed. The whole series was repeated 12-16 times. In addition, the subject uttered disyllabic nonsense phrases /CiCi/, where the first vowel is stressed, embedded in a meaningful sentence in isolation, where /C/ stands for the eight consonants mentioned above. This series was also repeated 12-16 times.

A bipolar hooked-wire electrode was used to record the EMG signals from the five intrinsic laryngeal muscles, INT, LCA, VOC, CT and PCA. The subject read the same utterance samples as those used for the fibreoptic experiment 12 to 16 times each in isolation (cf. section 5.5.3). The EMG signals were recorded on a multichannel FM recorder and the data were reproduced and averaged using a PDP-9 computer. The reproduced signals were sampled every 250 microseconds and digitized into 6-bit levels. The absolute values were taken and then integrated and smoothed over a range of 10msec. For a selected 10-14 samples for each item, the integrated values as functions of time were added together, with reference to a predetermined speech event, i.e. implosion (onset of closure) of the stop consonants under study.

Their results were as follows:

1 The activity of INT is suppressed for the production of aspirated stops, particularly for the voiceless aspirated stops, slightly suppressed for the voiceless unaspirated type, but not for the voiced unaspirated stops. As regards the timing of the suppression, the authors observed that it is different for different stop types. For example, with the voiceless aspirated type it is relatively early with suppression beginning

at about 200 msec before the onset of the stop closure, and INT activity gradually reaching its minimum at approximately 30 msec after the beginning of the stop closure. For the voiced aspirated stop, suppression begins later and follows a steeper course. For the voiceless unaspirated stop the suppression starts as early as, or a little earlier than, for the voiceless aspirated type.

2 There is a tendency toward suppression of VOC for all of the stop types, usually starting 30-40 msec before the beginning of the stop closure. The degree of suppression is more marked for aspirated than for unaspirated stops.

3 VOC activity tends to be higher for vowels following stops than those preceding them.

4 LCA activity is suppressed for all of the stop types but the timing varies; suppression occurs approximately 80msec before the beginning of the stop closure for the voiced types, but immediately before the beginning of the stop closure for voiceless types.

5 The timing of LCA activation after the suppression also differs depending on the stop type. The level of activity rises earlier for voiced types than for voiceless types.

6 For all stop types, there is a tendency towards suppression of CT activity starting approximately 100msec before the beginning of the stop closure. Except for the voiced unaspirated type, CT activity appears to increase again before the beginning of the stop closure (cf. Fig. 5.10.4, a-c).

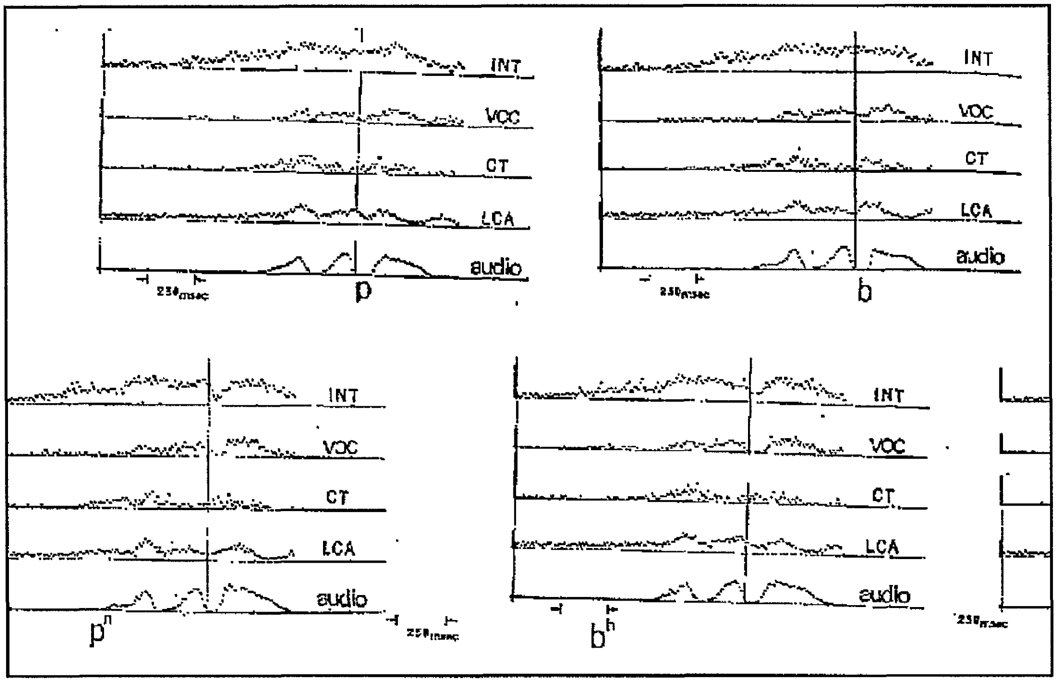



Fig. 5.10.4(a-d). Showing average EMG curves for the various stops. (A) Averaged EMG curves for intrinsic laryngeal muscles for [b] in the frame [thikiCi], (B) Averaged EMG curves for [bh], (C) Averaged EMG curves for [p] and (D) Averaged EMG curves for [ph].
Source: Kagaya and Hirose (1975:34-35).

Note: The vertical lines represent timing of suppression, i.e. where it was measured.

Hirose and Ushijima (1978) examined the laryngeal adjustments for voicing distinction in Japanese consonant production (voiced/voiceless) by means of EMG coupled with fibreoptic observation (cf. 5.5.3, also Hirose (1977)). EMG recordings were made using hooked-wire electrodes inserted into the five intrinsic laryngeal muscles - PCA, INT, CT, LCA, and VOC. The aim was to investigate the activity patterns of these muscles. In all cases, correct placement of electrodes was verified by monitoring an oscilloscope during various functional manoeuvres.

The EMG signals were recorded on a multichannel data recorder simultaneously with the acoustic signals and automatic timing markers. The signals were later reproduced and computer-processed to give an average pattern of muscle activity as a function of time.

The subject, who speaks the Tokyo dialect, read randomized lists of the test sentences sixteen times each. Each sentence embedded a test word in a frame. The test words used in the experiment are all meaningful Japanese words. The results of the EMG examination of the activity pattern of the five intrinsic laryngeal muscles were then compared (cf. Fig. 5.10.5).

Hirose and Ushijima observed that:

1 PCA (abductor muscle) and INT (one of the adductor muscles) show a reciprocal relationship regardless of the difference in phonetic environment: in other words PCA is always active for the production of voiceless sounds, during which INT is always suppressed. However the degree of PCA activation and corresponding INT suppression varies depending on the kind of environment.

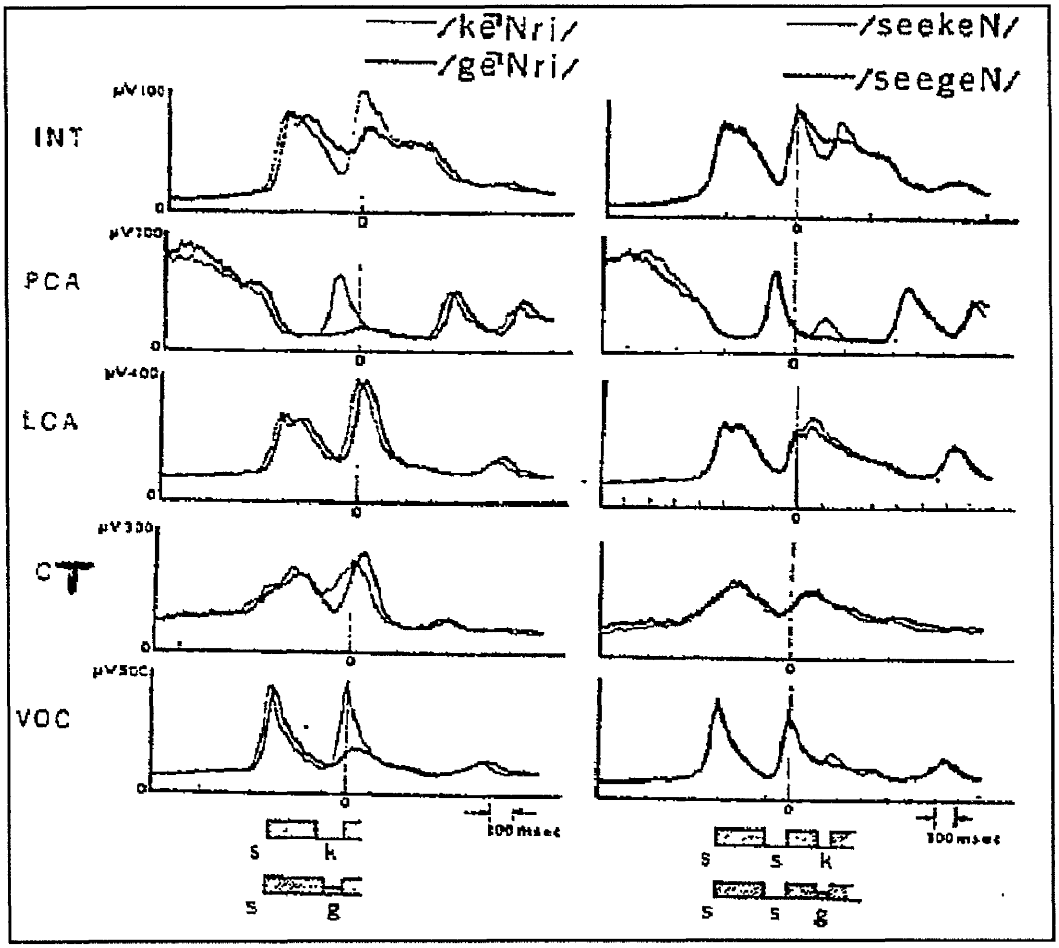



Figure 5.10.5: Averaged EMG curves for five intrinsic laryngeal muscles for the test utterances comprising /k/ and /g/ in the word-initial (a) and medial (b) positions. The line-up point for averaging was the onset of vowel after the consonant in question.

Hirose and Ushijima (1978:3).

2 The patterns for VOC and LCA were found to be the same. Both muscles are generally suppressed for consonantal segments, but the degree of suppression is more marked in the word-initial position (the authors suggested that this may be due in part to a word-boundary effect).

3 For most voiced-voiceless pairs, the general pattern of CT activity is similar and characterized by two

peaks separated apparently by suppression for the initial consonant of the test words. It is noted, however, that the degree of suppression is different depending on voicing of the initial consonant, in that suppression is less marked for the voiceless than for the voiced cognate. This difference is also related to the degree of reactivation after the suppression and is apparently more marked for the voiced cognate.

The authors noted that larger values of peak glottal width were associated with greater peak PCA activity (cf. section 5.5.3). In addition, the EMG patterns of suppression of INT, VOC, LCA, and CT for the consonantal segments were compared (cf. Fig. 5.10.6).

The authors summed up the results as follows:

> "INT suppression is consistently more marked for voiceless than for voiced cognates if the comparison is made in the same phonetic environment. On the other hand, the degree of suppression of LCA and VOC appears to be different depending primarily on the phonetic environment and not on voicing distinction. In the same environment, suppression appears to be more marked in VOC than in LCA. Suppression of CT is not remarkable in the word-medial position, whereas in the word-initial position, it is generally more marked for the voiced cognate" (cf. Hirose and Ushijima 1978:8).

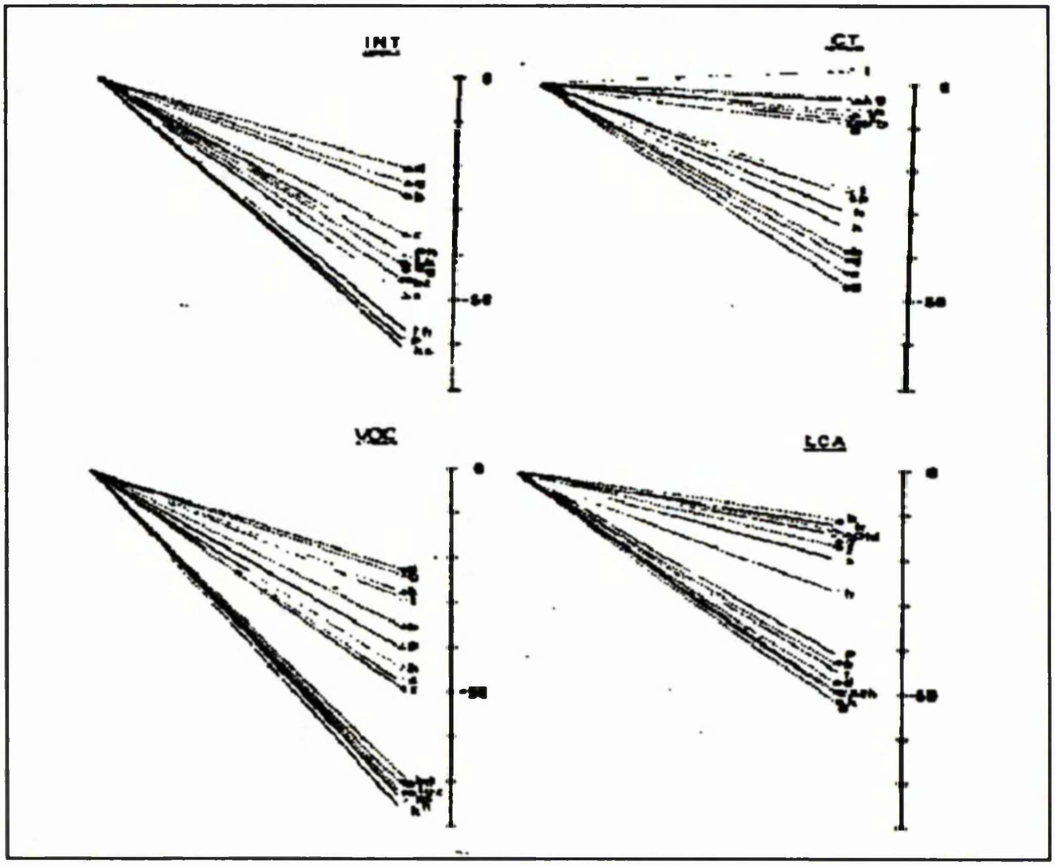


Figure 5.10.6: The degree of suppression of averaged EMG activity of four different muscles around the obstruents in the test utterances. O = word-initial voiceless consonants; dark circle means word-initial voiced consonants; empty -triangle means word-medial voiceless consonants and dark-triangle means word-medial voiced consonants.
Source: Hirose and Ushijima (1978:7).

### 5.10.4 Summary: Studies of Laryngeal Muscles Activity.

All the EMG studies discussed have revealed that there is a clear reciprocal pattern of activity between the adductor (closing) and abductor (opening) groups of intrinsic laryngeal muscles during speech production.

However, observation of individual languages which have phonemic contrast between voiced (aspirated/unaspirated) and voiceless stops (aspirated/unaspirated, strong and weak) have revealed slightly different results which are summarized as follows:

1 PCA shows increased activity during voiceless consonants and is suppressed during voiced ones in American English and Japanese (Hirose and Gay 1972, Hirose and Ushijima 1978). There is evidence that level of PCA activity is associated with degree of glottal opening (Hirose and Ushijima 1978).

2 INT shows increased activity during voiced consonants and is suppressed during voiceless ones in American English and Japanese (Hirose and Gay 1972, Hirose and Ushijima 1978). It is suppressed for weak and strong stops in word-initial position in Korean (Hirose, Lee, and Ushijima 1974). In Hindi, it is suppressed during voiced aspirated stops, more so for voiceless aspirated ones, slightly suppressed for voiceless unaspirated, but not for voiced unaspirated (cf. Kagaya and Hirose 1975).

3 VOC activity during consonants shows no clear difference of activity between voiced and voiceless segments, while it shows increased activity during vowels in American English and Japanese (the degree of suppression is more marked in word-initial position; cf. Hirose and Gay (1972) and Hirose and Ushijima (1978). In Hindi there is a tendency towards suppression for all the consonant types, more marked for aspirated than for unaspirated stops. The muscle shows greater activity during vowels following stops than those preceding (cf. Kagaya and Hirose 1975). In Korean, however, it shows a marked increase in activity before strong stops (cf. Hirose, Lee and Ushijima (1974).

4 LCA during consonants shows no difference of activity

between voiced and voiceless consonant segments, while it shows increased activity during vowels in American English and in Japanese. The degree of suppression is more marked in word-initial position (cf. Hirose and Gay 1972 and Hirose and Ushijima 1978). In Korean it shows a marked increase in activity before strong stops (Hirose, Lee and Ushijima (1974)). In Hindi, activity is suppressed for all of the stop types but timing differences between voiced and voiceless stops may be observed (cf. Kagaya and Hirose (1975).

5 CT shows a momentary increase in activity during vowels, with no appreciable difference of activity between voiced and voiceless segments in American English and Japanese (cf. Hirose and Gay 1972, Hirose and Ushijima 1978). In Hindi it is suppressed for all the stop types (cf. Kagaya and Hirose 1975). In Korean, it is characteristically suppressed in the middle portion of the consonant segment, but shows no difference of activity between aspirated, weak and strong stop types (cf. Hirose, Lee and Ushijima 1974).

## 5.11 Inverse Filtering

### 5.11.1 Principles and Apparatus.

Inverse filtering is a technique in which the radiated speech pressure waveform (obtained by means of an appropriate microphone and amplifier or pneumotachograph mask, cf. section 5.12.1 for explanation) passes through a filter having, as far as possible, a characteristic that is the inverse of the transfer characteristic of the radiating vocal tract. In order to recover the glottal pulse shape accurately, the original speech signal must be recorded and sampled without distortion throughout the frequencies of interest. The integral of the filtered oscillogram reflects the air flow at the glottis.

The technique was introduced in the late 1950s, primarily so that characteristics of the glottal source could be estimated at some distance from the source. It is based on the observation that the difference between the primary source of the sound (the glottis) and the sound at some distance is due to the modification it undergoes through the vocal tract to the lips and from the lips to the microphone. The technique thus aims to filter out the resonance effects of the vocal tract and the radiation at the lips in order to determine the characteristics of the acoustic signal that can be attributed to the glottal source. In other words, the effect of the vocal tract, which is basically the formant pattern, is subtracted from the speech wave form. The result is an indication of the glottal volume velocity flow.

Rothenberg (1973) describes the technique in the following words:

> "A direct technique for obtaining the glottal volume velocity waveform during voiced speech is the 'inverse filtering' of the radiated acoustic

waveform. As practised, inverse-filtering is usually limited to non-nasalized vowels or slightly nasalized vowels. The acoustic signal is recorded using a pressure-sensitive microphone having an exceptionally good low-frequency response, and the recorded waveform is passed through an 'inverse-filter' having a characteristic that is the inverse of the transfer characteristic of the supraglottal vocal tract configuration at that moment. The transfer characteristic of the supraglottal vocal tract is defined with the input to the vocal tract considered to be the volume velocity at the glottis" (Rothenberg 1973:1632).

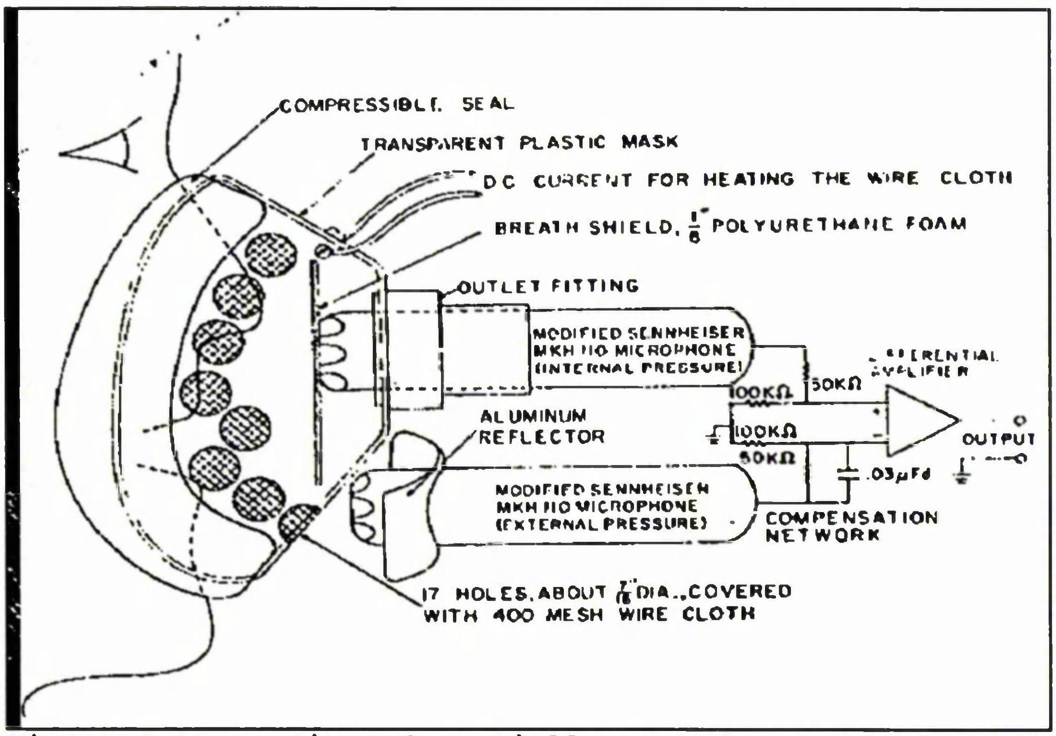



Figure 5.11.1: Circumferentially vented pneumotachograph mask.
Source: Rothenberg (1973:1634).

Since the development of the technique, improvements have been carried out by several researchers. For example, Rothenberg (1973 & 1977) recorded the volume velocity at the mouth, using a specially constructed circumferentially vented pneumotachograph mask as the input to the filters (cf. Fig. 5.11.1). With this modification only the resonance effects of the vocal tract need to be filtered out, as lip radiation effects are minimal when volume velocity is measured with a face mask.

Inverse filtering may be performed using a specially designed analog filter (as described by Miller 1959) or it can be carried out digitally, using a computer (Javkin et al. 1985 and Huffman 1985).

### 5.11.2 Advantages and Disadvantages of the Technique.

The advantages of the technique are as follows (cf. Miller (1959) and Rothenberg (1973, 1977 and 1981)):

1. There is no restriction on vocal organs as the technique is non-invasive;
2. Unlike the difficulties usually encountered in spectrographic analysis, the method offers an accurate way of measuring the natural period of the first formant independently of the effect of the harmonic spectrum itself;
3. When a mingograph (or similar writing device) is used, other signals related to phonation can simultaneously be recorded in addition to the airflow display;
4. It is possible when using an integrating circuit to determine the airflow rate of a given volume at a given time.

Miller (1959:673), Rothenberg (1973:1632, 1977:155 and 1981:88-89) and Sundberg (1982) list the following limitations of the technique:

1. There may be air leakage at the mask edges (if a face mask is used for recording) especially of expiratory speech air around the bridge of the nose, along the cheeks and under the chin due to articulatory movements, e.g. those of the jaws. This will result in an incorrect glottogram with a zero flow displacement.

However, this kind of error is not usually a problem during the articulation of sustained vowels;

2 The volume velocity is indicated only up to an additive constant; there can be no indication of zero flow because the initial zero level waveform is lost. Therefore the relative flatness of the waveform is generally used as a guide;

3 The method is highly susceptible to low-frequency noise. For example, the quality of the speech is usually affected by the enclosure of the mouth and the nose in the cavity of the mask. If the nasal section of the mask is not closed correctly it will be difficult to adjust the inverse filter properly: nasal resonance will affect the vocal tract and this effect will give an incorrect glottogram (cf. Miller 1959:673);

4 The filter characteristics for speech sounds which have their acoustic energies concentrated at higher frequencies, for example sibilants and other fricatives, are hard to determine, as amplitude calibration is difficult;

5 The method requires a knowledge of the supraglottal vocal tract under investigation for setting the parameters of the inverse-filter;

6 Errors are introduced whenever the mathematical model assumed for the supraglottal vocal tract does not accurately reflect the actual acoustic characteristics. This usually happens due to practical problems, for example, the difficulty of constructing some form of pneumotachograph transducer for the volume velocity at the mouth that is accurate over the entire frequency range of interest in voiced speech (cf. Rothenberg 1973:1633).

Rothenberg (1981:88) and Sundberg (1982), however, maintain that these problems can be overcome if the researcher continues to adjust the inverse filter parameters. This is done while observing the inverse filtered waveform during a repetitive playback of a few glottal cycles, and adjusting to minimize, or remove, any oscillations at the formant frequencies that occur during the relatively flat portion of the waveform at or near zero air flow which corresponds to the most closed portion of the glottal cycle.

### 5.11.3 Comparisons with other Techniques.

In a theoretical paper entitled Nature of the Vocal Cord Wave, which deals with the problem of precise representation of the transmission characteristics of the vocal tract, Miller (1959) attempted to define the filter characteristics of the vocal tract using glottal volume velocity waveforms and the area of glottal opening (as a function of time). This involves a comparison of (1) Inverse Filtering with (2) High Speed Motion Photography (cf. 5.4.3).

In a series of tests, he recorded several (number of subjects not stated) male subjects having fairly low pitches. The reason for this choice according to Miller was (1) more harmonics are obtained in the limited frequency band, and thus define the shape of the vocal wave more exactly, and (2) voices of this category tend to have longer closure times which gives a better setting of the ratio of the two distributive resistances. Samples of the steady state portion of the vowels were recorded through the condenser microphone onto a FM tape recorder and observed on an oscilloscope. In these tests, vowels were limited to front vowels series only which have the greatest spacing between the first and the second formant. The recordings were first processed by means of a sound spectrograph (cf. section 5.13.2). The narrow band analysis was used, primarily for computing the resonance frequency.

In applying the results of the analysis to the inverse network, the values were put in directly without altering the figure on the oscilloscope. According to the author, this was to avoid any tendency for the experimenter to adjust values in order to make the figure take on any preconceived shape. The only adjustment made was to select the ratio of the resistances to give the best horizontal adjustment to the region of closure.

According to Miller, his results obtained by the inverse filtering techniques show that:

1 The main excitation of the vocal tract uniformly occurs during vocal fold closure;
2 The main excitation of higher resonances occurs at the point of vocal fold closure; and
3 On harmonic analysis, the sharpness of the closure is directly related to the increase in high frequency energy.

The glottal flow waveforms were compared with area waveforms obtained from high speed motion photography. Miller notes considerable similarity between the two waveforms. See Figs 5.11.2 & 5.11.3. for sample illustrations of waveforms obtained during these experiments.

Rothenberg (1981) looked at the relationship of the glottal air flow and vocal fold contact area. He examined the correlation between the two variables and showed how information about the area waveform can help in interpreting the glottal air flow waveform, thereby improving the usefulness of the inverse filtering technique.

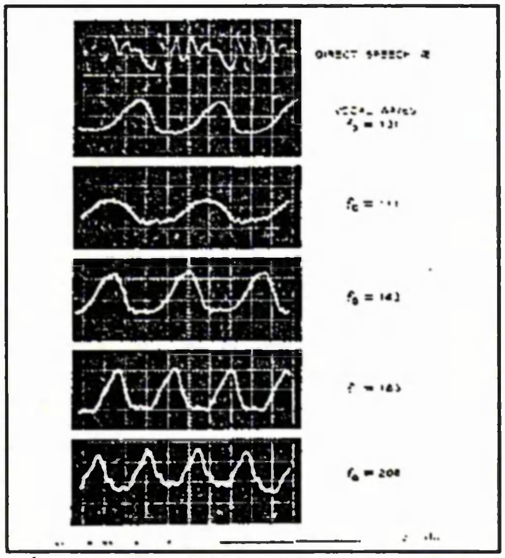


Figure 5.11.2: Vocal fold waves obtained from male speaker for the sound [ae] at different pitches.
Source: Miller (1959:670).

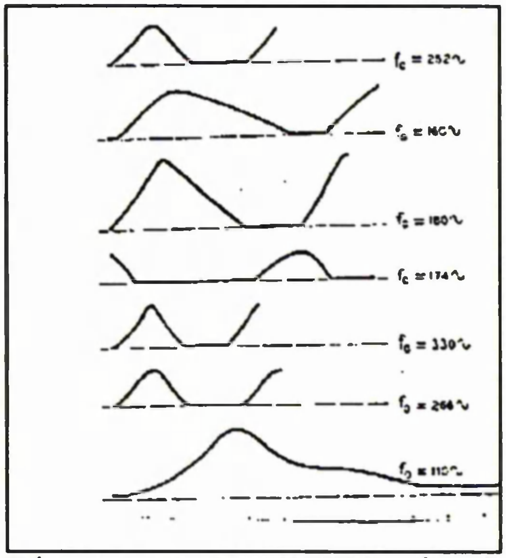


Figure 5.11.3: Typical vocal fold area waves as a function of time obtained from motion pictures of several speakers.
Source: Miller (1959:675).

He recorded a 40ms portion of a normal non-breathy vowel [ae] from a nonsense syllable [bae]. The waveforms for analysis, oral airflow signals from a circumferentially-vented pneumotachograph mask, were recorded simultaneously on a FM tape recorder. The mask covered only the mouth (not the nose) of the subject. The subjects, 3 adult males and 1 adult female, spoke into the mask. The glottal air flow signal was obtained by means of an analogue filter (cf. Rothenberg 1977), and the vocal fold contact area was estimated from a laryngograph (cf. section 5.9.3).

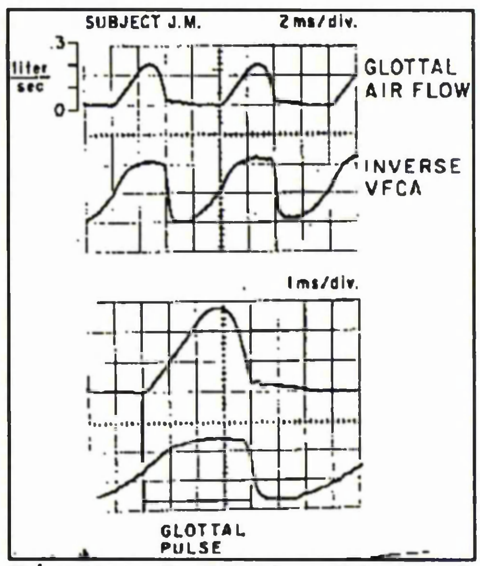



Figure 5.11.4: Glottal air flow and vocal fold contact area during /ae/ in the syllable /bae/.
Source: Rothenberg (1981:92).

Comparing the general shape of the waveforms obtained, Rothenberg noted a great deal of similarity between the waveforms as regards glottal pulse. Glottal pulse was defined on the basis of the air flow waveforms, as the period from the first sign of an increase in air flow associated with the glottal opening phase to the instant at which the negative slope during the closing phase is interrupted and a period of near zero slope begins. This definition of the glottal pulse is illustrated in Fig. 5.9.7.

Rothenberg summarizes his findings as follows:

1 During the "closed" portion of the glottal cycle, the glottal air flow waveform is rather flat, at or near its minimum flow during the cycle (cf. Fig. 5.11.4).
2 During the beginning of opening of the vocal folds (signalling the start of the next glottal cycle) the air flow wave is seen to rise indicating that there is greater flow of air now beginning or passing through the glottis.
3 At the upper margins of the air flow wave it is assumed that the vocal folds are fully open (less vocal fold contact area would generally correlate with more air flow).

### 5.11.4 Some Applications of the Technique in Speech Research.

Rothenberg (1973, cf. also Rothenberg 1968) describes an experiment in which he obtained volume velocity waveforms at the glottis during vowels produced with modal voice, breathy voice and creaky voice. Volume velocity was recorded from a specially constructed, circumferentially vented wire screen pneumotachograph mask which provided a time resolution of 1/2 msec (see Fig. 5.11.1, Rothenberg

1973:1634).

Two male adults were recorded while phonating the vowels [a] and [ae] in the context of /b/ vowel /p/, using three different voice qualities. Filtered waveforms for the various tokens were obtained. The formant frequencies for input to the inverse filter were measured at a relatively steady-state portion, usually 40-50msec, and for representative sequences an average value was calculated. The measurements were used to check for a drift in vowel articulation, as sometimes occurred (according to the author) when the pitch or loudness was varied during the sequence. The examples analyzed were selected from 300 syllables that were produced. To ensure a negligible error arising from the frequency response limitation of the mask, examples were selected only of vocalizations with fundamental frequency below about 125Hz. For visual inspection and measurement, the waveforms were traced using a hot-wire oscillograph. The glottal waveforms were discussed with regard to their characteristic shape.

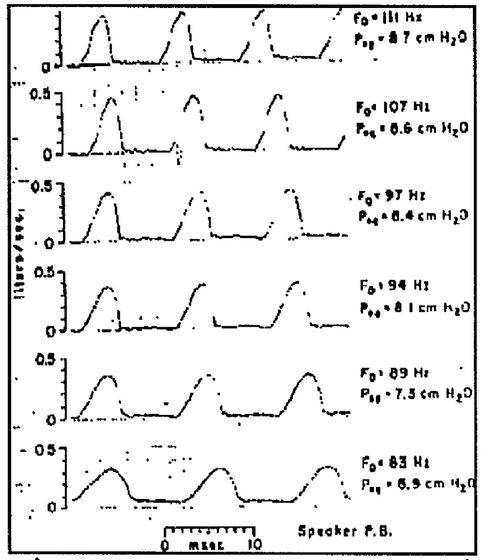


Figure 5.11.5: Inverse-filtered glottal volume velocity waveforms during a series of syllables with decreasing fundamental frequency. Source: Rothenberg (1973:1641).

To make comparisons easy, the examples were mostly taken from one speaker and waveform shapes were defined against the waveform obtained for modal voice. The waveform of modal voice was observed to have a marked flat or almost flat region, which the author suggests is due to the coming together of all or part of the vocal folds. Here, minimum air flow is less than 15% of the peak airflow. See Fig.

5.11.5 which shows typical waveforms selected from a series of syllables /bap/ produced with modal voice and decreasing fundamental frequency. In other words, the peak glottal conductance (conductance defined as volume velocity divided by pressure) tended to remain constant and there was regular, sharply defined periodicity of waveform.

A comparison of the results showed the following general pattern for the different phonation types.

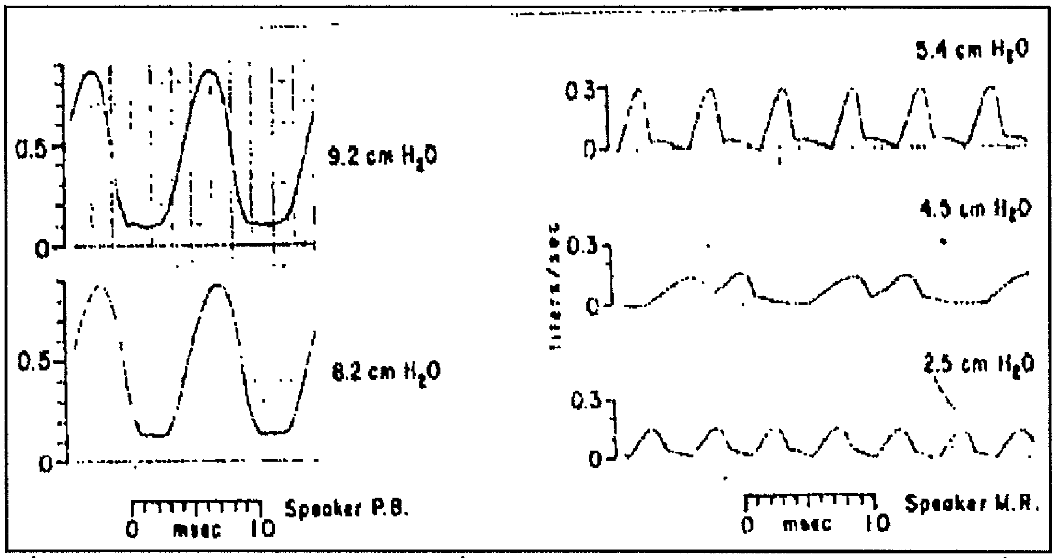



Figure 5.11.6: Inverse-filtered glottal volume velocity waveforms from syllables with different voice qualities (a) breathy voice and (b) creaky voice.
Rothenberg (1973:1641 and 1643).

1 Breathy voice showed an airflow waveform with a much smoother or relatively longer plateau with no obvious contact of the vocal folds (cf. Fig 5.11.6a).

2 Vocal fry (creaky voice) showed an airflow waveform with a double pulsing pattern of voicing indicating stronger compression at the glottis (cf. Fig. 5.11.6b).

Huffman (1985) discussed the properties of glottal waveforms obtained using the inverse filtering technique for Hmong breathy and non-breathy vowels [a] and [aw]. Hmong is a Sino-Tibetan language which has been described as having seven tones including one "breathy tone" (cf. Table 5.11.1 for illustrations of this seven way contrast).

Table 5.11.1: Illustrations of tonal contrast in Hmong

| Tone | (quality) | Word and Gloss | |
|---|---|---|---|
| high | (normal) | $tau^{55}$ | 'pumpkin' |
| rising | (normal) | $tau^{35}$ | 'to dam up (water)' |
| mid | (normal) | $tau^{33}$ | 'to be able' |
| low | (normal) | $tau^{22}$ | 'axe' |
| checked | (normal) | $tauʔ^{31}$ | 'bean' |
| falling | (normal) | $tau^{42}$ | 'sp. of grass' |
| low | (breathy) | $tau^{32}$ | 'to follow' |

Source: Huffman (1985:5).

Three male speakers between 16 and 18 years of age were recorded reading a list of 12 words twice each. Combined oral and nasal flow were recorded for each speaker using a special face mask (cf. section 5.12.1). The oral flow recording served as the input to the inverse filtering and was digitized with a sampling rate of 18000 samples per second. The speech signals recorded during the experiment were also used for detailed acoustic analysis (cf. section 5.13.4).

Individual words were identified and stored separately for analysis. A portion of each vowel token was selected for this purpose. The location within the vowels of the chosen portion was motivated by the properties of the inverse-filtering.

Properties of the glottal flow waveforms which were thought likely to reflect differences attributable to phonation contrast were investigated both quantitatively and by qualitative visual inspection of the waveforms. Results were illustrated in various figures and tables. For a

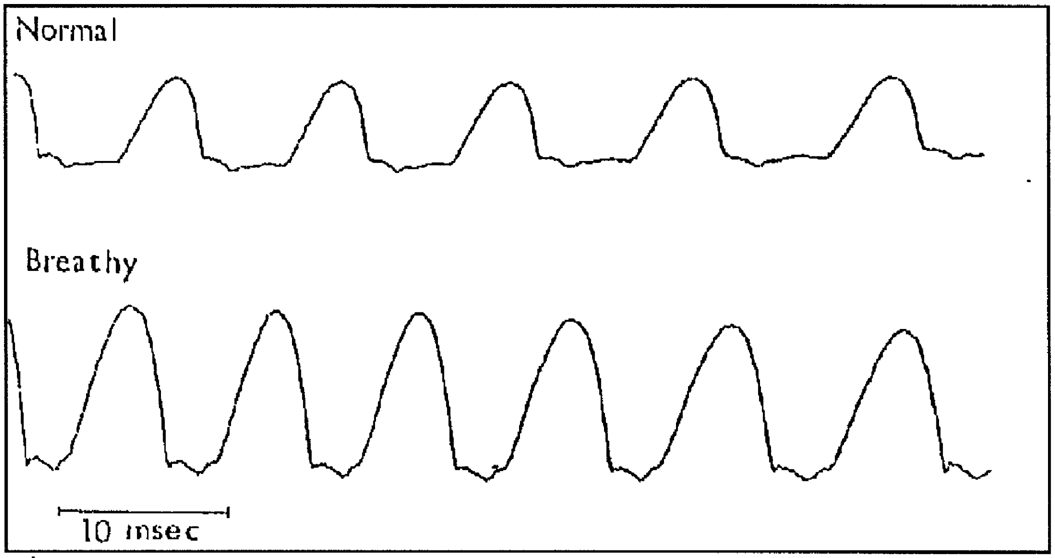


Figure 5.11.7: Sample glottal flow waveforms.
Source: Huffman (1985:14).

general idea of the way pulse shapes can vary, cf. Fig. 5.11.7 where illustrations of normal and breathy voice waveforms are given.

Huffman's comparison of the breathy and non-breathy vowels indicated substantial differences between the two vowel categories. A summary of her results is as follows:

1 In the qualitative investigation she reports that the characteristic shape of the glottal waveforms for breathy phonation shows that it has greater flow amplitude than modal phonation (cf. Fig. 5.11.7);

2 The glottal flow waveforms were measured with the aid of the "glottal" program developed at UCLA (cf. Fig. 5.11.8 which illustrates the marking process on a normal voiced vowel). Three variables were assessed:

   1 Duration of vowels;
   2 Closure duration ratio (defined as the ratio of the duration of the closed phase of the glottal flow pulse to the total duration of the pitch period);
   3 The ratio of the slopes of the falling and

rising branches of the open phase of the glottal pulse. The rising and falling slopes were determined from the slopes of the tangents to the rising and falling branches of the flow pulse. These tangents were estimated using the average derivative over 7 points in the middle of the rising and falling branches.

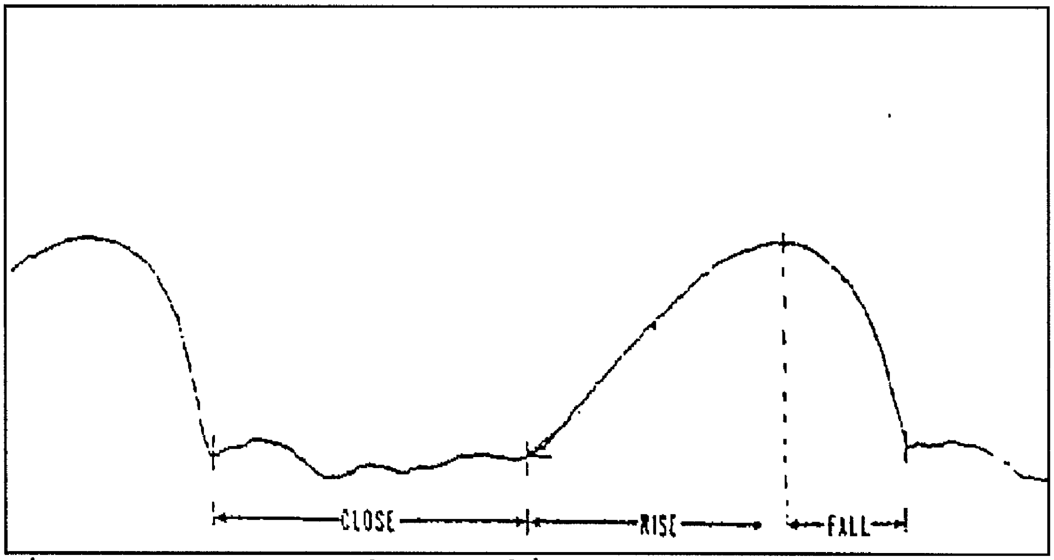



Figure 5.11.8: Waveform marking.
Source: Huffman (1985:15).

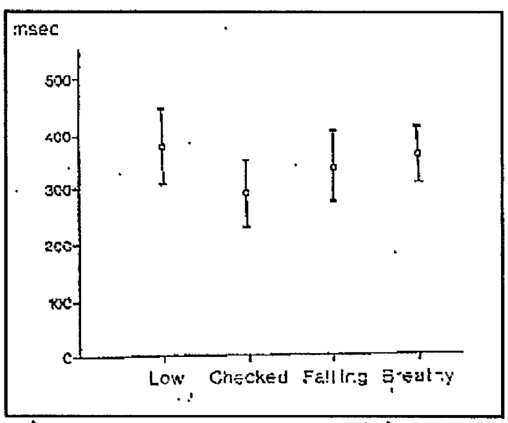



Figure 5.11.9: Duration of vowels (means and standard deviations).
Source: Huffman (1985:10).

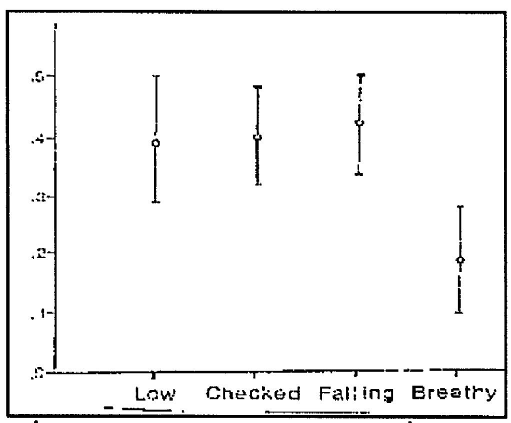



Figure 5.11.10: Duration of vowels (means and standard deviations).
Source: Huffman (1985:10).

The closure duration ratio and the slope ratio were calculated for five pulses of each token. From these values mean closure duration ratio and mean slope ratio were computed for each token. See Figs. 5.11.9, 5.11.10 and 5.11.11 which show means and standard deviations for vowel duration, closure duration ratio and slope ratio pooled across speakers for the four tones in Hmong.

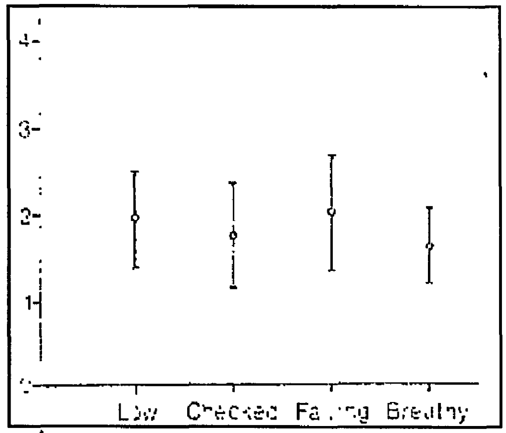


Figure 5.11.11: Slope ratios (means and standard deviations).
Source: Huffman (1985:16).

Her quantitative investigation showed that:

1 The average duration of the vowels read at the four tones of interest shows that the vowels read with checked tone are shorter than the normal (low, falling) and breathy tones. As regards the normal (low, falling) and breathy tones, the low tone is on average longer than both the breathy and falling tones; there was no significant difference in duration between falling and breathy tones (cf. Fig. 5.11.9);

2 With regard to closure duration ratio, the non-breathy tones are very close in value, with a mean closure duration of about 40% of the pitch period. The breathy tone, on the other hand, has a mean closure duration ratio of about half this, at slightly less than 20% of the pitch period (cf. Fig. 5.11.10. The figure also shows that there is considerable variation in flow pulse closure duration ratios);

3 Fig. 5.11.11 shows means and standard deviations of the slope ratios pooled across all speakers. The figure shows that the ratio of falling to rising

slopes was a less effective indicator of phonation differences. The shape of the breathy tone is not much more symmetrical than that of the non-breathy tones. An analysis of variance showed that none of these tones were significantly different from each other on this measure.

With regard to the laryngeal configurations that would account for the kind of phenomena discussed above, Huffman suggested that further research is needed. She says,

> "though the differences in duration ratio for breathy and normal voice vowels in Hmong are statistically significant, they are of an order of magnitude so small that they could not be controlled directly" (Huffman 1985:23).

In her view, it is still possible, as has been discussed in the literature for a long time, that variation in glottal stricture contributes to the differences in closure duration.

Bickley (1982) observed the glottal volume velocity waveforms for Gujarati and !Xóõ and reported that the properties of the glottal flow waveforms are distinctive for different phonation types. In the study she recorded a series of words read by ten native speakers of !Xóõ. The series contained a 'clear' vowel /a/ and a breathy vowel /a̤/. In addition, recordings were made of four native speakers of Gujarati reading several words. The list they read contained words with clear vowels, words with breathy vowels and a series

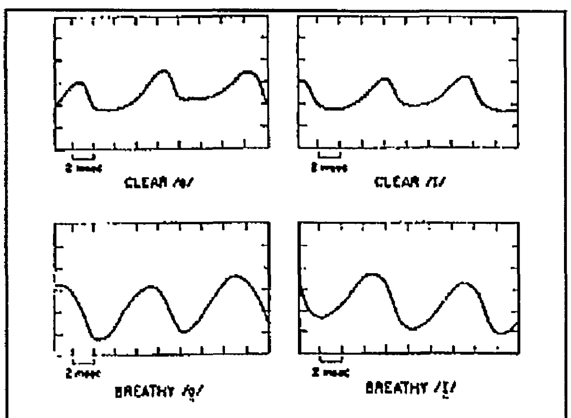


Figure 5.11.12: Sketches of glottal waveforms of clear and breathy /a̤/ and /I/ !Xóõ as obtained from inverse filtering process.
Source: Bickley (1982:77).

of minimal pairs containing clear and breathy vowels. The aim of the study was to try and gain further insight into the nature of the glottal waveforms for the breathy vowels. For the clear and breathy vowels analysis was made of the steady portion of the vowels. A qualitative comparison of the shapes of the four waveforms for the two phonation types showed that the vowels are different in terms of the waveform shapes in both languages (cf. Fig. 5.11.12).

Bickley reports her findings as follows:

1. The glottal waveforms of the clear vowels showed slower opening than closing phases, abrupt closure, and a closed phase that occupied approximately one third of the period of vibration;
2. The glottal waveforms for the breathy vowels exhibited similar opening and closing phases, resulting in a more symmetric shape. Closure was less abrupt and the closed interval was shorter;
3. Interpreting the result physiologically, Bickley suggested that at no point is there a complete closure of the glottis in the breathy vowel productions.

Javkin and Maddieson (1983) have also used the inverse filtering technique to study the characteristics of linguistically contrastive creaky and modal voice in Burmese. Burmese is a tonal language and four different type of tones are distinguished: (1) rising, (2) falling, (3) creaky and (4) glottal stop tone. The words used in the study represents the four tonal contrasts listed above.

The study reports and discusses the characteristics of the glottal air flow waveforms which are considered essential in distinguishing creaky vowels from non-creaky phonation. The subject was a male native speaker of Burmese in his early twenties. He read a list of fifteen words five times each. Three tokens were discarded because the signals were not good, hence measurements were made on 72 tokens.

The recording was continuously monitored on an oscilloscope in order to ensure that relatively constant amplitude was maintained, and the data was charted using an Oscillomink chart recorder. Measurements on the Oscillomink output were made for the last 20 cycles of each token in the case of words with rising or falling tone. Tokens of creaky and stop tone words were usually too short to contain 20 cycles, so measurements were made on the highest available multiple of 5 periods. The measurement points used are shown in Fig. 5.11.13.

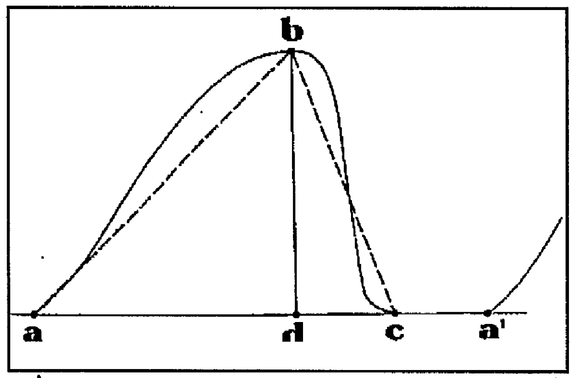



Figure 5.11.13: Measurement points on each cycle of the inverse filtered waveforms. Slope of dotted lines a-b and c-b was calculated from distances a-d, d-c and b-d. Source: Javkin and Maddieson (1983:121).

Point a is the beginning of the rising branch. Point b is the highest point of the cycle. Point c is the end of the falling branch. Point d is where the perpendicular from the highest point intersects a line between a and c. The distance a-d reflects the duration of the rising branch. The distance d-c reflects the duration of the falling branch. The distance b-d reflects the maximum amplitude of the cycle. The distance c-a' gives the duration of the closed portion of the cycle, while the distance a-a' gives the total duration of the cycle.

Approximations of the slopes of the rising and falling branches for each cycle were obtained by dividing the amplitude measure (b-d) by the rising and falling durations. This method provides only an approximation of the slopes (contrast the method of Huffman (1985), described above). The absolute differences between each period and the preceding period were obtained in order to represent period to period variation in pitch (jitter) (cf. Table 5.11.2).

Table 5.11.2: of five measures of glottal activity in Burmese tones.

| T. | Rising branch duration $\bar{x}$ | sd | Falling branch duration $\bar{x}$ | sd | Rising branch slope $\bar{x}$ | sd | Falling branch slope $\bar{x}$ | sd | Jitter $\bar{x}$ | sd |
|---|---|---|---|---|---|---|---|---|---|---|
| R. | 0.89 | 0.09 | 0.50 | 0.04 | 0.43 | 0.07 | 0.77 | 0.16 | 0.18 | 0.13 |
| F. | 1.03 | 0.19 | 0.46 | 0.05 | 0.43 | 0.09 | 0.88 | 0.12 | 0.36 | 0.19 |
| C. | 0.74 | 0.16 | 0.37 | 0.04 | 0.66 | 0.12 | 1.14 | 0.28 | 0.31 | 0.20 |
| S. | 0.70 | 0.31 | 0.28 | 0.06 | 0.60 | 0.14 | 1.40 | 0.45 | 0.44 | 0.26 |

Source: Javkin and Maddieson (1983:122).

Key:

T = Tone    $\bar{x}$ = Mean    R = Rising
F = Falling    C = Creaky    S = Stop
sd= Standard Deviation

The glottal waveforms were discussed with regard to the waveform characteristic patterns:

1 Rising and falling branch durations;
2 Rising and falling branch slopes; and
3 Jitter, calculated as the absolute difference between each period and the preceding period for each cycle.

A comparison of the results showed the following general patterns (cf. Table 5.11.2):

1 The duration of the rising branch of the glottal cycle tends to be shorter in the creaky and stop tones than in the rising and falling tones;
2 The duration of the falling branch also tends to be shorter in the creaky and stop tones;
3 As for the slopes, both the rising and falling branches of the cycles tend to be steeper in the creaky and stop tones than in the rising and falling

tones. The slopes are somewhat more variable in these tones, particularly the falling slope of the stop tone tokens;

4 Jitter is relatively low in the rising tone, and relatively high in the other three tones.

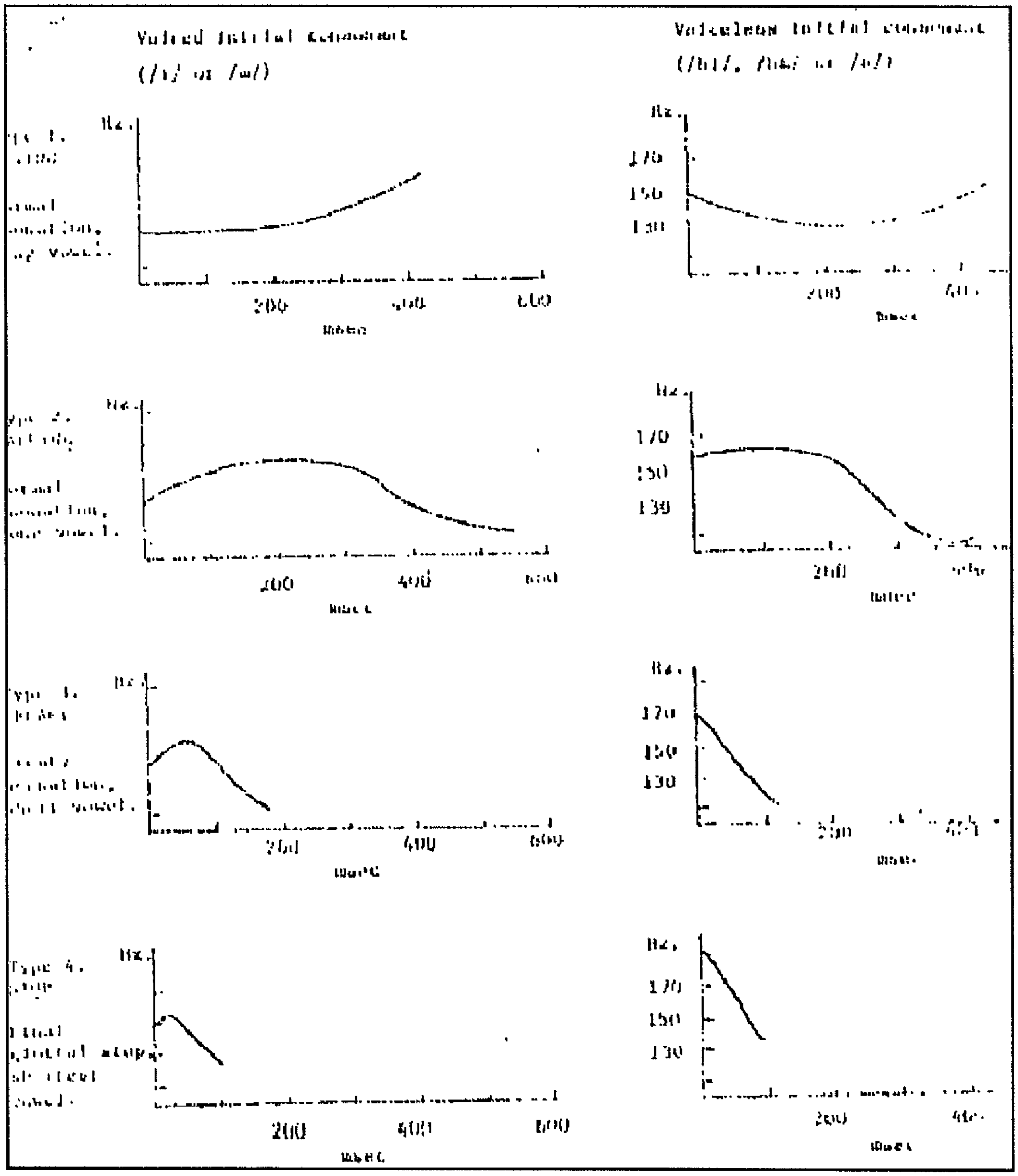



Figure 5.11.14: Pitch and duration of Burmese tones. Contour shown is the average of several tokens of representative words spoken in isolation. Contour begins at vowel onset.
Source: Javkin and Maddieson (1983:116).

Physiologically, Javkin and Maddieson suggested that it is possible that the steeper rising slope pattern of the creaky and stop tone is associated with some tendency towards higher tension in the intrinsic laryngeal musculature.

## 5.12 Aerometry

### 5.12.1 Principles and Apparatus.

Aerometry refers to techniques for measuring oral and/or nasal air flow during the production of speech sounds. This will be affected by a change in glottal adjustments. It should therefore be possible to make inferences concerning the state of the glottis by measuring these variables. Air flow is a measure of volume of moving air per unit of time and is often measured in millilitres per second.

The apparatus most commonly used for measurements of oral (and nasal) air flow is a pneumotachograph, a face mask unit with individual flow meters (pneumotachometers) for nasal and oral cavities (cf. Borden and Harris 1981:230). Sometimes transducers can be built into it. The device employs a shaped hollow tube with a fine wire mesh screen across it which acts as a resistance element. A microphone may be inserted into a small hole.

The principle of measuring air flow rate is based on the fact that the pressure drop across the resistance (the mesh screen), which is caused by an air stream, varies linearly with the flow rate under certain conditions. Thus, the flow rate can be determined from measurements of pressure difference (cf. Farquharson and Anthony 1970:813 and Nihalani 1974:201).

An alternative device is the Hot-Wire Anemometer. Hirano (1981) describes this system in the following way:

> "The hot-wire anemometer is based on the principle that the heat removed from a hot-wire by a gas stream is linearly related to the square root of the velocity of the gas stream and that the voltage drop across the wire is linearly related to the square root of the heat removed. Thus, the air flow velocity is calculated by measuring the electric voltage drop across the

hot-wire" (Hirano 1981:27).

Recording is usually carried out with the subject seated in a chair and then asked to phonate into the mask. The mask is fitted tightly to the subject's face by means of head-gear. The output from this is recorded onto a writing device such as a mingograph or a tape recorder (cf. Fig. 5.12.1 which illustrates the recording set-up used by Dart 1984:2).

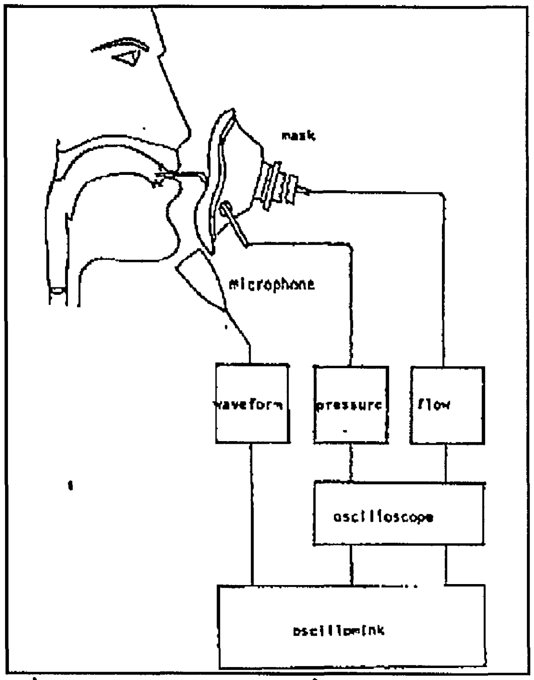


Figure 5.12.1: Diagram of experimental apparatus. Source: Dart (1984:2).

5.12.2 Advantages and Disadvantages of the Technique.

The main advantages of the technique are (cf. Keating 1984, Javkin et al. 1985:88 and Rothenberg 1973:1632-1634 and 1977:155):

1 The technique offers minimum discomfort to the subject;
2 It does not interfere with normal phonation as no object is inserted into the subject's oral or nasal tract.

The main disadvantages of the technique are (cf. Rothenberg 1973:1632-1634 and 1977:155):

1 Air leakage at the mask edges may occur during recording;
2 It may not always be possible to find a face mask that can fit all subjects (ideally, one should have a selection of masks, as at Reading University);
3 Speaking through a mask can affect the subject's natural way of speaking (especially if he/she is not a phonetician with laboratory experience of speaking through a face mask);
4 It is sometimes difficult to show the cut-off point of voicing on the waveform.

### 5.12.3 Some Applications of the Technique in Speech Research.

In a phonetic study of breathy (murmured) vowels in Gujarati, Fischer-Jørgensen (1967) discussed vocal adjustments in their production. She made use of a number of instrumental techniques, including an aerometer. The other techniques include an acoustic analysis (cf. section 5.13). Three subjects read a list of words and sentences into an aerometer which was used to record air flow for measurements.

Besides giving a detailed presentation of the way in which the air flow recordings were obtained she devotes a section to the discussion of some of the more general characteristic patterns obtained. For visual inspection the airflow traces were recorded using a mingograph. The curves indicate the amount of air passing through the glottis per unit of time. Measurements were carried out to determine the following:

1 maximum airflow;

2 average airflow; and

3 duration.

The results were presented in the form of a table (cf. Table 5.12.1).

Table 5.12.1: Air Flow in ml/sec.

| | maximum air flow | | | average air flow | | |
|---|---|---|---|---|---|---|
| speaker | RD | RT | GU | RD | RT | GU |
| No. of tokens | 552 | 676 | 214 | 504 | 644 | 214 |
| breathy vowel | 18.6 | 17.2 | 36.6 | 15.1 | 12.1 | 30.5 |
| clear vowel | 8.9 | 11.4 | 25.7 | 7.2 | 8.3 | 19.3 |
| difference | 9.7 | 5.8 | 10.9 | 7.9 | 3.8 | 11.2 |
| % increase | 109 | 55 | 46 | 110 | 46 | 60 |

Source: Fischer-Jørgensen (1967:86).

The results show a clear difference between non-breathy and breathy vowels. For all the speakers breathy vowels have a consistently higher maximum airflow than the corresponding non-breathy vowels. With regard to durational difference, breathy vowels were found to be longer than non-breathy vowels, and this difference was noticed for all speakers.

With regard to glottal configuration Fischer-Jørgensen suggested that the increased airflow of breathy vowels can be explained either by a wider glottis, or by increased activity of the expiratory muscles or by both. Fischer-Jørgensen arrived at this conclusion based on the result of a laryngoscope used in conjunction with stroboscopic investigation of the glottal opening of one of the subjects. The subject's glottis was observed while phonating the vowel /a/. The result shows an opening in the rear part of the glottis for the breathy vowels. Fischer-Jørgensen remarked:

> "On the physiological level murmured vowels are characterized by a strong air flow. This is a very stable feature. It seems to be due to the presence of a small opening in the rear part of the glottis. Since murmured vowels have, in spite of this opening, the same physical intensity as clear vowels, a stronger activity of the expiratory muscles may be assumed" (Fischer-Jørgensen 1967:138).

Aerodynamics have been used to study phonation contrasts in other languages. Hardcastle (1973) examined Korean stops (cf. section 5.5.3 for an explanation of these stops) in initial position and suggested that the feature "tensity" is indispensable in interpreting some of the acoustic and physiological differences in the manner of articulation of the stops.

In support of this claim he provides both acoustic and aerodynamic data (for a discussion on acoustic data see section 5.13.3; here only the latter will be discussed). The correlation of aerodynamic features with the 3-way manner distinction in the stop consonants was examined using data supplied by a single native speaker of the Seoul dialect. The subject read a total of 126 words in a randomized order. The rate of air flow from the mouth was measured by a pneumotachometer. A hard copy record of the air flow tracing was obtained by means of an Oscillomink.

The airflow signals obtained from the various stop series provided measurements of the rate of airflow associated with each of the stop types during their release; in addition, visual inspection of the air flow tracings revealed qualitative differences between the three stop types.

Hardcastle observed that, for each place of articulation, the three stop consonants differed consistently from each other. The results showed that maximum air flow was:

1 Highest for aspirated stop;
2 Medium for weak stop;
3 Lowest for strong stop.

See Table 5.12.2.

Table 5.12.2: Air-flow rates (in l/s).

| | Range Minimum | Maximum | Mean |
|---|---|---|---|
| /P/ | 0.40 | 1.20 | 0.82 |
| /p/ | 1.10 | 2.50 | 1.88 |
| /ph/ | 3.20 | 4.50 | 4.07 |
| /T/ | 0.60 | 1.00 | 0.84 |
| /t/ | 1.00 | 2.30 | 1.54 |
| /th/ | 3.10 | 4.50 | 3.96 |
| /K/ | 0.40 | 0.70 | 0.50 |
| /k/ | 1.00 | 1.80 | 1.36 |
| /kh/ | 2.90 | 4.20 | 3.66 |

Source: Hardcastle (1973:269)

As regards qualitative differences between the traces for the three stops, see Fig. 5.12.2. These are associated with the maximum rate of air flow. The qualitative difference is quite clear; in all cases there was an upward progression in the flow-rate from strong to weak and then to aspirated stop.

With regard to the physiological adjustments that take place during the production of the three stops, Hardcastle hypothesised that the relative width of the glottis is not the same for the three stop types (the claim being made is that a wider glottis may result in a higher rate of airflow). Hardcastle therefore suggested that the strong stop was characterized by greater tension both in the vocal folds and in the supralaryngeal cavity. I quote:

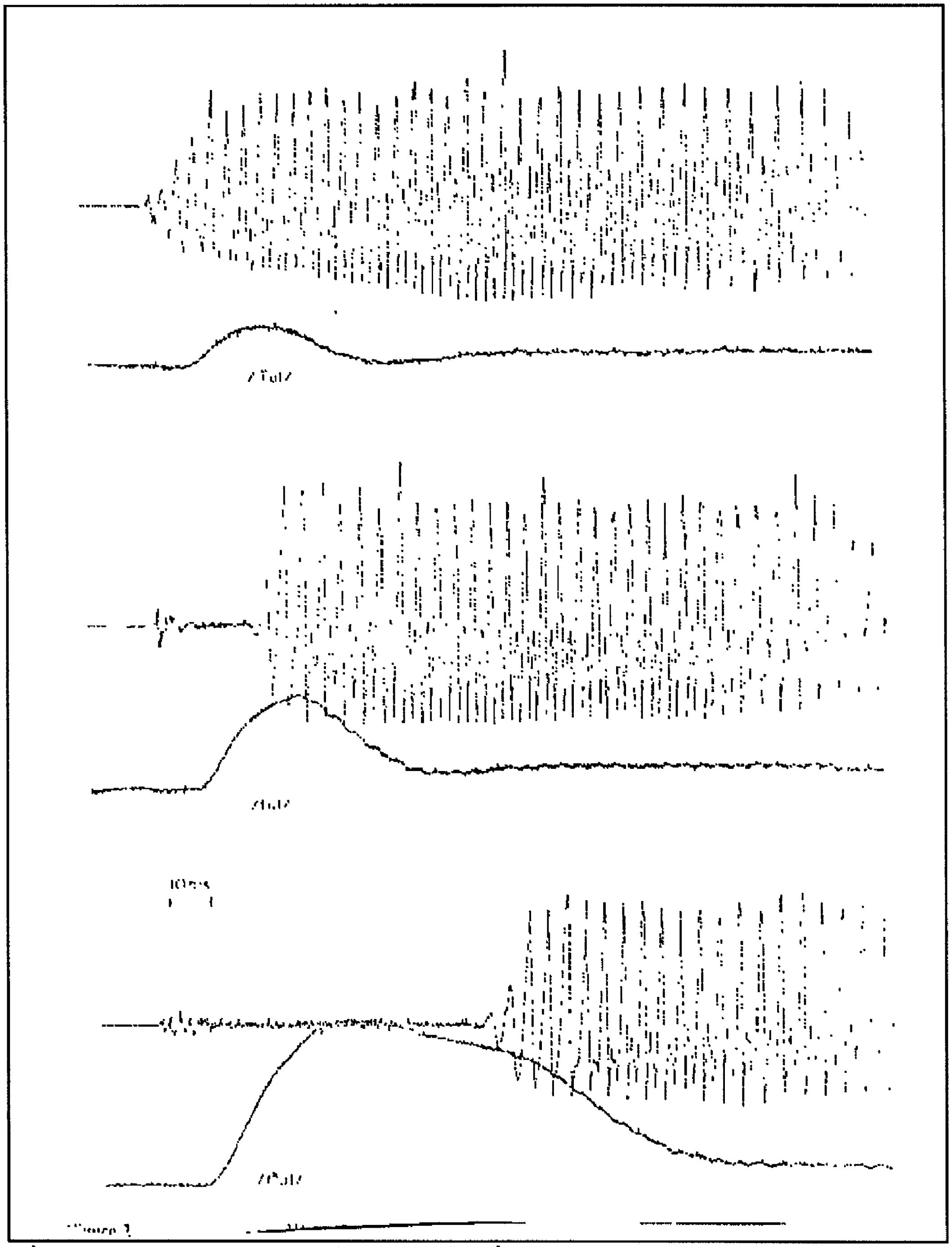


Figure 5.12.2: Waveform and air flow traces for the three test words.
Source: Hardcastle (1973:270).

> " ... the muscles of the vocal folds and pharynx are stiffened by an increase in isometric tension and the glottis is tightly adducted" (Hardcastle 1973:269)

("isometric tension" means a possibility where a muscle contracts without changing its length).

In the weak stop he says: " ... the vocal folds are set loosely in a slightly abducted position" (271), and the aspirated stop was characterized by a wide open glottis during the occlusion phase of the stop. Studies made by means of fibreoptic photography of the vocal folds have confirmed this claim (cf. section 5.5.3 on fibreoptics, particularly Kagaya's (1971) study on Korean stops). Kagaya notes that the glottis was tightly closed immediately prior to the vowel onset following strong stop, slightly adducted for weak stop and wide open for aspirated stop.

Dart (1984) examined the phonetic nature of the Korean strong and weak stops (cf. section 5.5.3 for a definition of these terms). She measured oral air flow and intraoral air pressure during the production of these segments and then compared her results with the predictions of a computer-implemented aerodynamic model (based on an electrical analogue).

During recording, oral (and nasal) air flow was recorded using a modified respiratory mask (cf. Fig. 5.12.1) with a fine stainless steel gauze exhibiting a known resistance through which the outgoing air must pass. The air flow was calculated from the pressure difference across the gauze.

Ten native speakers, six male and four female, all between 16 and 18 years of age, acted as subjects. Seven of the subjects were speakers of the Seoul dialect, two of the Kwangwon Do dialect and one of the Kyansang Nam Do dialect. Four minimal pairs containing the two stops were recorded three times in the order weak-strong and three times in the reverse order. The consonants were limited to bilabials only. After each recording session the air pressure and the air flow devices were calibrated, the pressure by use of a standard U-tube manometer and the air flow by introducing a known voltage. Both signals were monitored on an oscilloscope and recorded on an Oscillomink ink-writer (cf.Fig.5.12.3 which shows a typical Oscillomink print out; the arrows show the points measured).

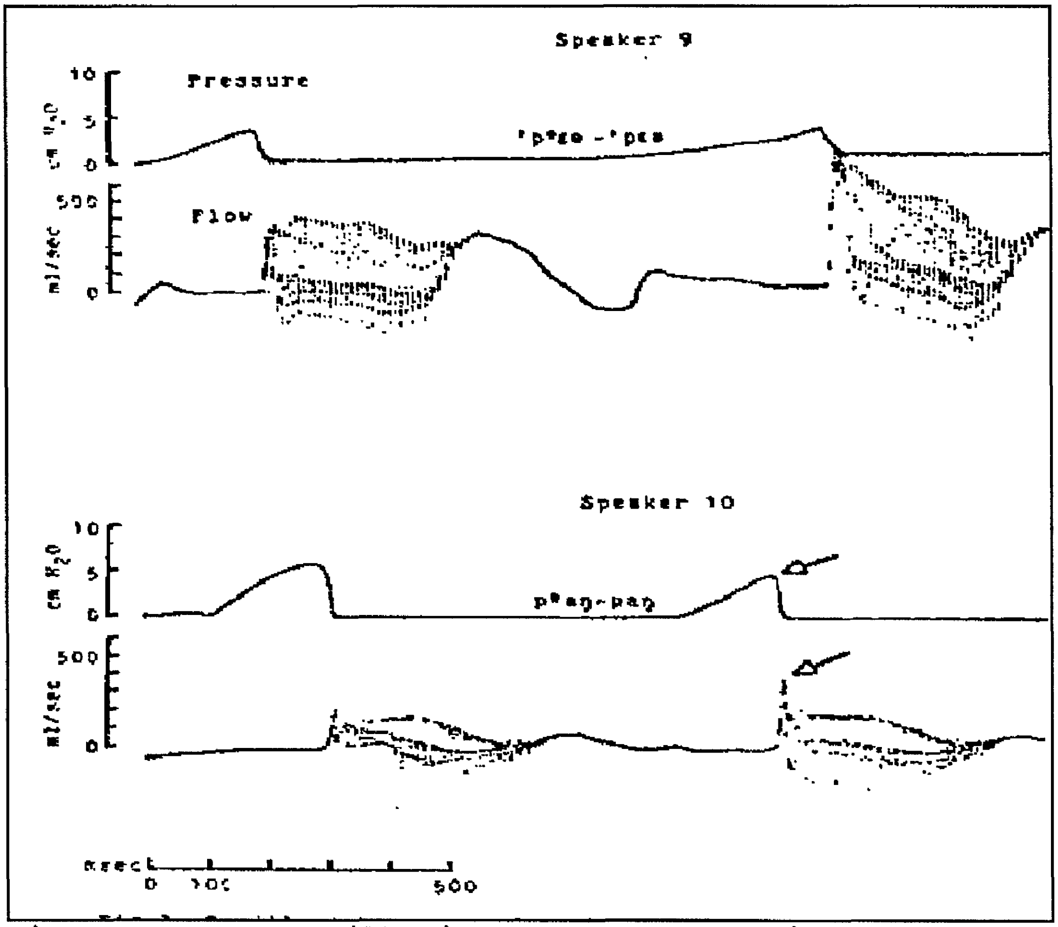



Figure 5.12.3: Oscillomink traces of oral air pressure and flow during the production of two different Korean word pairs. Arrows indicate points measured.
Source: Dart (1984:6).

Three variables measured were:

1 Peak oral pressure during occlusion;
2 Peak oral flow immediately after articulatory release;
3 Closure duration (closure was considered to begin as the oral pressure curve began to rise and to end at the beginning of the flow rise at release).

Results were presented in the form of numbers and figures and are summarized as follows:

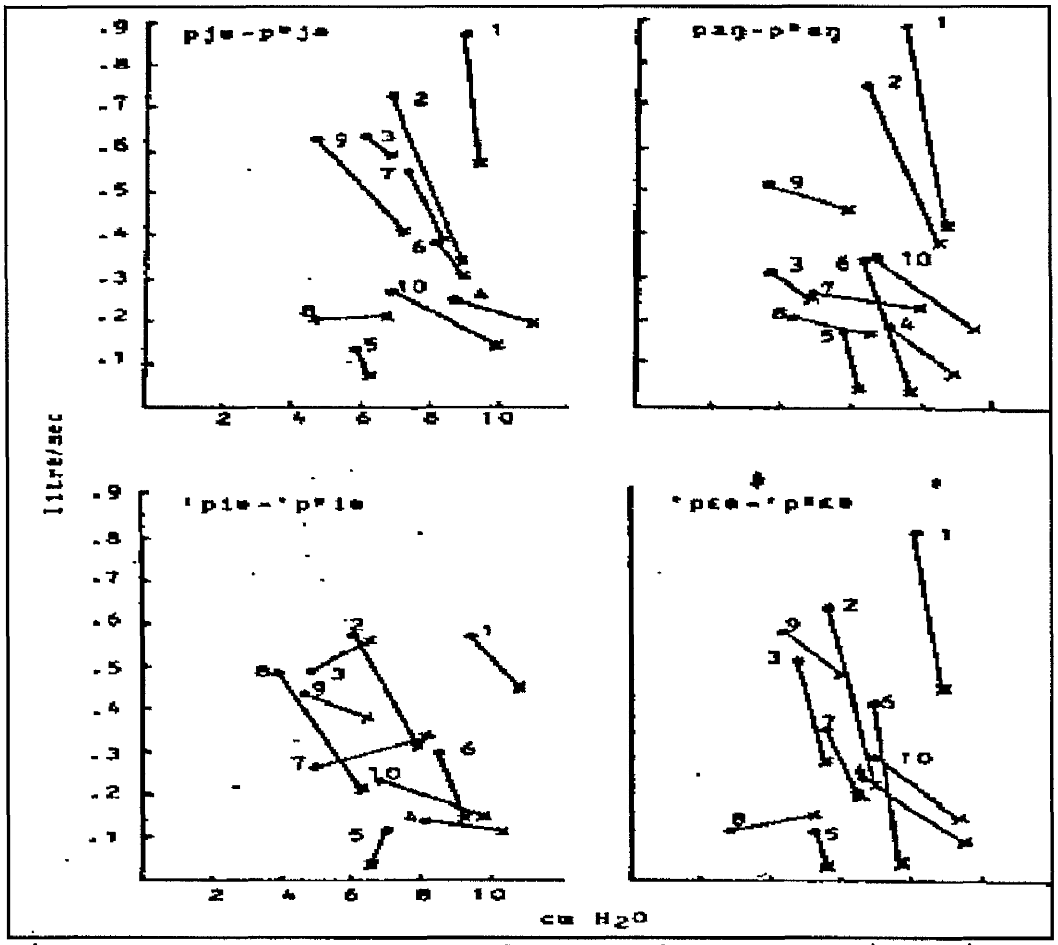



Figure 5.12.4: Pressure and flow of weak (solid points) and strong (crossed) stops of ten speakers for each word pair.
Source: Dart (1984:7).

1 The measures of peak oral pressure during the closure and the peak of oral flow immediately after the articulatory release show a great deal of inter-speaker variation in terms of the absolute values of pressure and flow. However, the results showed that there is a clear distinction between the two stop types in the speech of all of the speakers (cf. Fig. 5.12.4). The overall tendency was for the strong stops to have higher oral pressure and lower

oral flow values than their weak counterparts, which had low oral pressure and high oral flow values in the same environment. Some speakers seemed to make the distinction primarily on the basis of pressure while others showed less pressure difference and more flow difference between the types; there were also differences between the various word pairs within the speech of individuals;

2 As regards closure duration, Dart found that the strong stop closures were considerably longer than the weak stop closures. The average closure duration of all the strong stops was 188.25msec and that of the weak stops was 133.5msec.

Dart's conclusions concerning the nature of the articulatory difference between the stop categories were based on her attempt to simulate the observed pressure and flow data using a computer-implemented model based on an electrical analogue as mentioned above. We shall not discuss the details of the model here.

When only differences in glottal area function and duration were modelled, the strong and weak stops differed with regard to pressure and flow as expected but the magnitude of the differences was too small. Agreement was improved when the model was refined to take into account possible differences in the tension of the vocal tract wall. Still better agreement, especially for some speakers, was obtained when differences in respiratory activity and larynx height were modelled as well.

Dart concluded that the greater intraoral pressure and lower oral flow rate observed for the strong stops could in part be explained with reference to more closely adducted vocal folds, but that differences in the tension of the vocal tract walls, a more rapid increase in respiratory muscle force, and (for some speakers) larynx lowering or other supraglottal cavity expansion should be postulated as well.

Nihalani (1974) made an aerodynamic examination of Sindhi stops. In this language, besides a contrast in voicing and unvoicing, aspiration and unaspiration, there is a contrast between compression and rarefaction with regard to the type of air pressure and air flow used in the production of the explosive and implosive sounds. For measuring the oral air flow, a pneumotachograph was used (cf. Fig. 5.12.5).

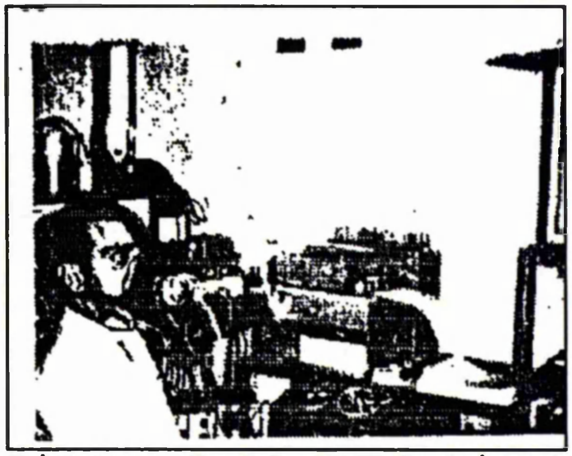


Figure 5.12.5: Subject positioned for recording. Source: Nihalani (1974:202).

A multichannel mingograph ink-writer running at a speed of 10 cm/sec was used to display simultaneously air pressure, airflow through the mouth, pitch, larynx waveforms and audio signal. The experimenter acted as subject reading minimal pairs representing all the stop sounds in syllable initial position. In cases where minimal pairs were not found in the language a nonsense word was used. Another list of 8 words containing minimal pairs contrasting explosive with implosives was also read. Each word was uttered three times and the average of three measurements was calculated.

On the mingogram traces, vocal fold activity is represented by several ripples. A mid-line was drawn through these ripples by hand (cf. Fig. 5.12.6). The maximum pressure was measured on this mid-line. Results were discussed based on the mean values of air pressure (cf. Table 5.12.3).

The following measurements were made from the pressure traces of each of the utterances:

1 The magnitude of supraglottal pressure at the onset of closure; and
2 The magnitude of subglottal pressure at the release of closure.

The subglottal pressure was recorded with the aid of a small catheter inserted through the nostril and the pharynx into the oesophagus. The anterior portion of the catheter was connected to a semi-conductor pressure transducer and placed just above the bifurcation of the trachea. A similar pressure transducer unit was inserted through the right nostril and placed in the oral-pharyngeal cavity just above the vocal folds, in order to pick up pressures in the supraglottal cavities.

These pressure transducers converted the pressure signals into an electrical signal which was further amplified and converted to a graphic display as channels 2 and 3 of the mingograph ink writer. Two pressure systems were calibrated against a water monometer. The pressure recordings were scaled so that pressure of 10cm $H_20$ was recorded by vertical deflection of 1cm on paper.

A comparison of the results, based on the measurements taken on the mingogram traces, led Nihalani to arrive at the following conclusions:

1 For all the stop sounds investigated, air pressure in the lungs was higher than atmospheric pressure;

2 Sindhi implosive sounds are produced with negative pressure which is generated in the mouth during the closure period, and the release of the mouth closure

Table 5.12.3: Mean values of peak sub- and supra-glottal pressure measurements for syllable-initial implosives/explosives.

| Stop sound | Sub-glottal pressure cm $H_2O$ run 1 | run 2 | run 3 | total | aver-age | Supra-glottal pressure cm $H_2O$ run 1 | run 2 | run 3 | total | aver-age |
|---|---|---|---|---|---|---|---|---|---|---|
| b_ | 10 | 10 | 9 | 29 | 9.7 | -1 | -4 | -3 | -8 | -2.7 |
| b | 13 | 14 | 14 | 41 | 13.7 | +10 | +10 | +9 | +29 | +9.7 |
| ḍ_ | 14 | 14 | 11 | 39 | 13.0 | -5 | -4 | -2 | -11 | -3.7 |
| ḍ | 16 | 15 | 11 | 42 | 14.0 | +9 | +10 | +9 | +28 | +9.3 |
| j_ | 13 | 13 | 15 | 41 | 13.7 | -4 | -9 | -8 | -21 | -7.0 |
| f | 18 | 15 | 15 | 48 | 16.0 | +11 | +11 | +12 | +34 | +11.3 |
| g_ | 16 | 12 | 14 | 42 | 14.0 | -4 | -11 | -5 | -20 | -6.7 |
| g | 19 | 12 | 13 | 44 | 14.7 | +9 | +13 | +14 | +36 | +12.0 |

Source: Nihalani (1974:205).

b = explosives
b_ = implosives

initiates an inward flow of air. This indicates the rarefaction of the air in the supraglottal cavity as a result of the lowering of the larynx (cf. Fig. 5.12.6 and Table 5.12.3);

3 Sindhi explosive sounds are produced with positive pressure which is generated in the mouth during the closure period and the release of the closure initiates an outward flow of air (cf. Fig. 5.12.7 and Table 5.12.3).

Similarly, Nihalani (1986), (which is basically the same study as his 1974 paper apart from the comparison with Hausa and Kalabari) investigated the phonetic properties of implosive sounds in Sindhi and Hausa and demonstrated that implosives in Sindhi are produced with a significant ingressive airflow in contrast to the implosive sounds found in Hausa, in which this was not apparent. This finding, according to the author, contrasts with some of the findings of Ladefoged (1968 and 1971); that is, in many of the languages he (Ladefoged) investigated there was seldom any ingressive airflow.

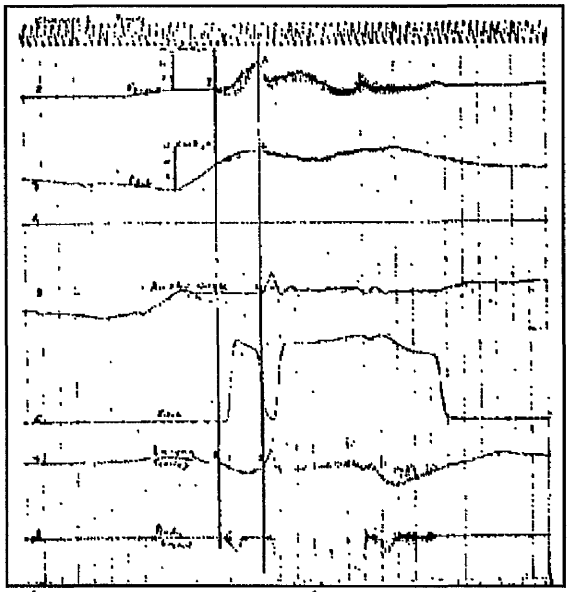


Figure 5.12.6: Mingogram of [barO] (burden).
Source: Nihalani (1974:204).

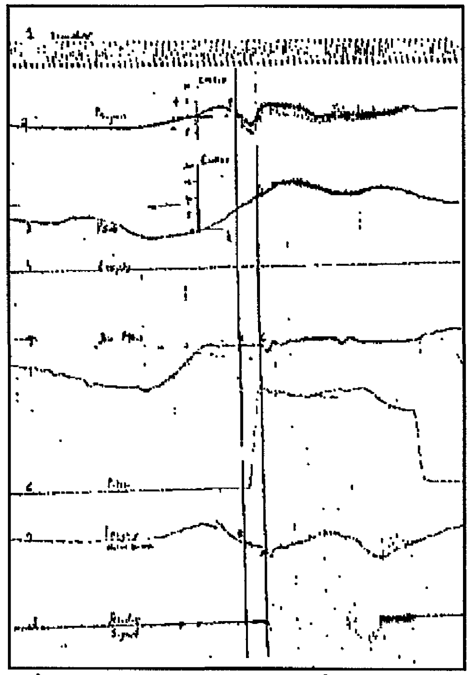


Figure 5.12.7: Mingogram of [b'arO] (a child).
Source: Nihalani (1974:207).

Nihalani based his conclusions on Sindhi on air flow recordings made using a pneumotachograph in conjunction with an eight-channel mingograph ink-writer. For Hausa and Kalabari he based his conclusions on spectrographic analysis and on results of aerodynamic investigation reported by Ladefoged (cf. section 5.13.3 for a detailed discussion on these two languages. Here only Sindhi is going to be discussed). The researcher acted as the sole informant, reading minimal pairs of 16 Sindhi words containing the implosive sounds in syllable initial position. Each word was uttered three times and the average of the three measurements was taken (cf. Table 5.12.4).

To discuss some of the differences between the selected consonants, measurements were made of the following variables:

1 Duration of voicing during the articulation of both the implosive and explosive stops;

2 Direction of air flow.

Table 5.12.4: Duration of voicing in milliseconds.

| Sound | Run 1 | Run 2 | Run 3 | Total | Average | Difference |
|---|---|---|---|---|---|---|
| b' | 70 | 50 | 60 | 180 | 60 | |
| b | 120 | 120 | 110 | 350 | 117 | 57 |
| d' | 90 | 70 | 80 | 240 | 80 | |
| ḍ | 160 | 160 | 140 | 460 | 153 | 73 |
| ƒ | 100 | 110 | 90 | 300 | 100 | |
| ɟ | 120 | 120 | 130 | 370 | 123 | 23 |
| g' | 80 | 100 | 90 | 270 | 90 | |
| g | 110 | 140 | 140 | 390 | 130 | 40 |

Source: Nihalani (1986:117).

The upper consonant in each pair is "implosive"; the lower "explosive".

The printout from the mingograph was used to determine the second variable mentioned above.

1 A comparison of implosive and explosive stops in relation to the duration of voicing was made. Nihalani notes that the implosive stops are different from their explosive counterparts in that they have a shorter voicing duration. The duration of voicing of the implosives ranges from one- half to four fifths the duration of voicing in the corresponding explosives (cf. Table 5.12.4). Interpreting the results in aerodynamic terms, Nihalani suggested that this is attributable to the fact that,

> " ... the constant transglottal airflow tends to destroy the partial vacuum in the supraglottal cavity by raising the pressure in the mouth. It is because of this aerodynamic constraint that the voicing in implosives cannot be maintained for as long a period as in the case of corresponding explosives where the inverse relation between the voicing and supraglottal pressure can be maintained by incomplete velo-pharyngeal closure so as to help absorb the transglottal airflow. Therefore, the duration of voicing of the implosive stops is much shorter

than that of the corresponding explosive stops" (Nihalani 1986:118).

2 As regards the direction of airflow, he found that the mingographic record for implosives showed an ingressive flow due to a downward movement of the larynx while the vocal folds are vibrating. He remarked,

> "The oral air flow records clearly indicate a very significant volume of air being sucked in at the point of release in the articulation of implosive sounds in Sindhi" (Nihalani 1986:119).

On comparison of the airflow waveforms of Sindhi with those of Hausa, Nihalani observed that Sindhi implosives are different from those of Hausa, in that a very significant volume of air is sucked in at the point of release during their articulation. He writes:

> "Sindhi implosives involve the suction of the air from outside, in contrast to the implosives observed by Ladefoged in which there is no such suction" (Nihalani 1986:119).

Roach (1980) investigated the articulatory movements of laryngeal closure using the electrolaryngograph and airflow measurement (cf. section 5.9.3, also his 1973 study of the glottalization of English /p/, /t/, /k/ and /tʃ). He examined the larynx movement and measured the time taken to effect a stop closure at four different places of articulation (bilabial, alveolar, velar and glottal stop). The parameters examined were:

1 Time of each closure and
2 Characteristic pattern of larynx movement.

For this purpose, Roach recorded a number of subjects producing voiced or voiceless vowel [a] preceding stop consonants in English. The items recorded in the experiments were as follows:

1 (with voiced vowel) /ap/, /at/, /ak/, /ab/, /ad/, /ag/, and /a?/ twice.

2 (with voiceless vowel, [b, d, g] pronounced as whispered) /hp/, /ht/, /hk/, /hb/, /hd/, /hg/, and /h?/ twice.

The time taken for each closure was then calculated (the time measure equals the time taken from the subject's being instructed to perform a particular articulatory closing movement to the moment when airflow from the vocal tract was judged to have effectively ceased as a result of the closure being completed).

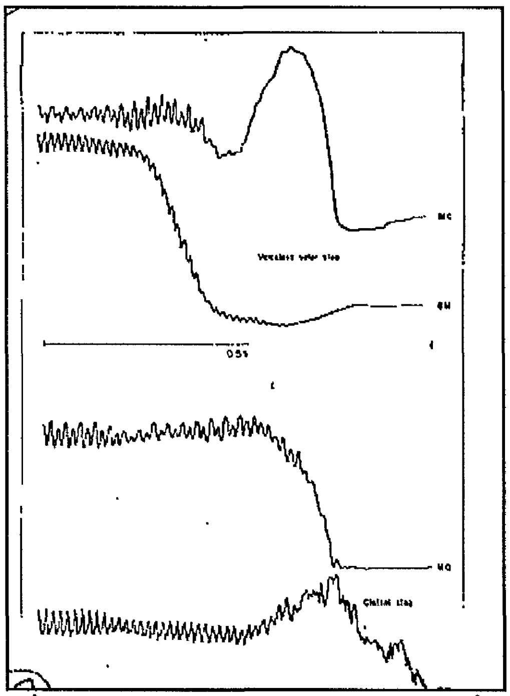


Figure 5.12.8a: Average air flow traces for AS's 40 repetitons of [ak] (upper pair of traces) and [a?] (lower pair)
Source: Roach (1980:310).

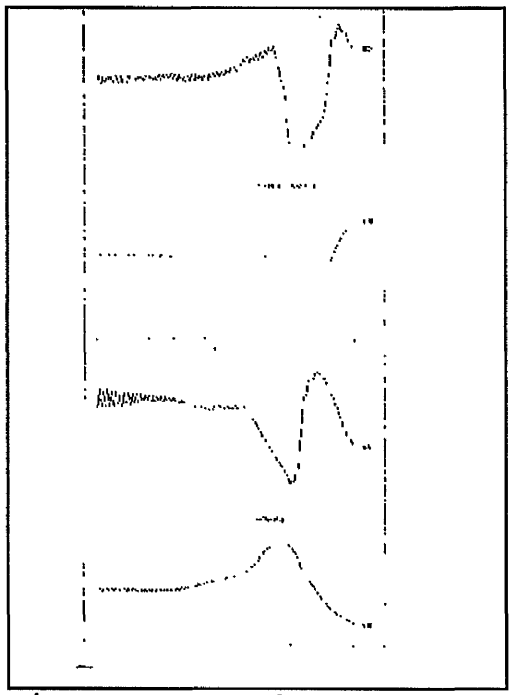


Figure 5.12.8b: Averaged airflow traces for comparison with MG's [ap] (upper) and [a?] (lower). The traces represent the average of 40 repetitions.
Source: Roach (1980:311).

(GM) means "gross movement" of larynx and (MO) means "mouth output".

Comparing the results, Roach notes that the time taken for laryngeal closure of glottal stop was longer than for the oral stops. He remarked:

> "The time measurements given indicate strong support for a conclusion that the "glottal stop" is not produced in a shorter time than other voiceless plosives, and in fact usually takes rather more time than other plosives" (Roach 1980:312).

See Table 5.12.5 which shows the results of the measurements with mean reaction times and standard deviations.

A comparison of the gross movement of the larynx during the production of the stop types shows that for the glottal stop the larynx moved upwards while for the other stop types the larynx moved downwards. See Fig. 5.12.8 which show traces of gross movement of the larynx during the production of /k/ and /p/. The trace labelled "GM" is the output of the electrolaryngograph showing the gross movement of the larynx.

Table 5.12.5: Mean and standard deviation of reaction times for various stop closures.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ap | at | ak | ab | ad | ag | aʔ | aʔ |
| | 198 | 251 | 282 | 193 | 204 | 289 | 296 | 351 |
| sd | 31 | 56 | 72 | 22 | 37 | 35 | 38 | 79 |
| | hp | ht | hk | hb | hd | hg | hʔ | hʔ |
| | 197 | 237 | 247 | 208 | 204 | 295 | 310 | 383 |
| sd | 34 | 47 | 70 | 36 | 44 | 36 | 60 | 38 |
| | ha | | | | | | | |
| | 227 | | | | | | | |
| sd | 45 | | | | | | | |

For each item, N=50, times are in msec.

Source: Roach (1980:308).

## 5.13 Acoustic Analysis.

### 5.13.1 Principles and Apparatus.

This section presents some studies based on the investigation of many aspects of speech signals. A brief account of some of the methods available to us for recording and displaying speech signals is also given. The main purpose is to show some of the principles upon which data collection, display and analysis is performed.

Before work can be carried out on speech signals there is a need for some kind of permanent record of the signals. As Tatham remarked:

> "Since any scientific investigation requires careful control and interpretation of the data there can be no question that it becomes very important to have some kind of permanent record of the phenomena under investigation, if only to repeat the experiment or check the validity of any inferences we might make" (Tatham 1984:1).

With rapid growth in electronic technology it is possible to measure acoustic aspects of speech reliably and relatively easily in the laboratory. Speech measurement systems consist of two main sections.

1 The input device which gathers the raw data. The input device is usually an electronic device (recorder) with a microphone.

2 The display/analysis device. This device is usually a computer and/or oscilloscope (cf. Agnello 1975, Howard 1988 and Tatham 1984). The oscilloscope is usually required for temporary visual presentation purposes such as monitoring during an experiment, or for finding one's place (level) in a recording prior to making some kind of permanent record of data (cf. Fig.

5.13.1, which shows an oscilloscope.

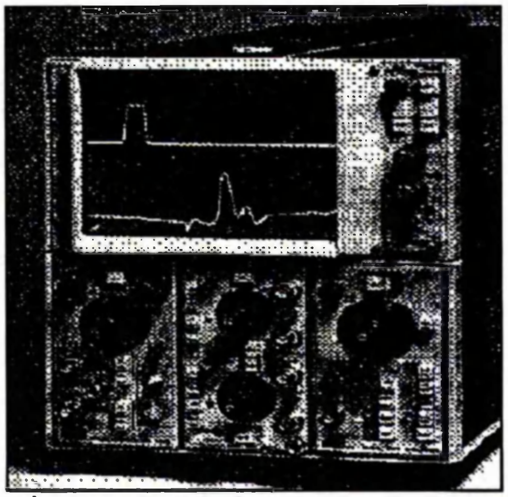


Figure 5.13.1: A dual beam oscilloscope.
Source: Painter (1979:138).

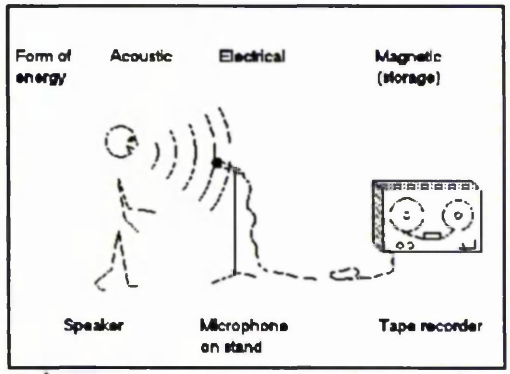



Figure 5.13.2: The principle of tape recording.
Source: O'Brien (pers comm).

In work on speech there are generally two ways to make permanent records of an acoustic signal. They are:

1 A recording of the actual data, obtained as closely as possible to the original conversion of the information into electrical signals. This is usually done on magnetic tape (cf. Fig. 5.13.2 which shows the principle of tape recording).

2 A visual recording of the final output of any electrical or other processing of the data for inspection and measuring by the investigator.

For permanent displays (records) we need such things as:

1 Pen recorders, which provide a permanent trace on paper charts.

2 Ink-jet recorders. The signal we want to display is sprayed onto paper by directing a jet of ink towards the paper, literally spraying a trace.

3 Ultra-violet Recorders, which use a very narrow beam of ultra-violet light to write a tracing representing the waveform of the incoming data signal on paper which is photo-sensitive in the ultra-violet region.

4 Thermal Recorders. They work by applying the incoming data signal to arrays of very fine heat-generating elements placed in contact with an unrolling paper. The paper is heat sensitive and colour (usually blue or black) is revealed whenever the paper comes into contact with a heated element (cf. Tatham 1984).

The advantages and limitations of particular methods are discussed in Liberman (1977), Ladefoged (1967a), Painter (1979), Tatham (1984) and Howard (1988).

### 5.13.2 Spectrography.

Under this heading are included:

1 The traditional Sound Spectrograph and
2 Computer-implemented digital analysis, including the Digital Spectrograph.

The discussion of sound spectrography that follows is based on the account given by Painter (1979), Howard (1988) and Lieberman and Blumstein (1988).

#### 5.13.2.1 The traditional Spectrograph.

The traditional sound spectrograph (cf. Fig 5.13.3) was the instrument of choice for analysis of speech from 1940 through to the 1970s when the computer-implemented methods began to be substituted. It was developed at the Bell Telephone Laboratories in connection with work on speech synthesis (cf. Farmer 1984, and Lieberman and Blumstein 1988). The device is probably the single most useful tool for quantitative analysis of speech, providing a number of different types of display. It produces the well-known three-dimensional spectrogram (which is a picture of the acoustic output from the speaker), showing the relation between amplitude, frequency and time, using filters of various band widths. Frequency (on the vertical axis) is plotted against time (on the horizontal axis), and the darkness of the markings relates to signal amplitude. The sound spectrograph essentially performs two operations:

1 It records the speech signal on the machine (input) and
2 It analyzes the signal recorded.

A short section of the sound to be analyzed (about 2.2 sec) is recorded on the magnetic drum of the instrument (the record level must be kept within certain limits). The signal to be analyzed is usually from a tape recorder playing a previously recorded signal. The sound spectrograph machines that are commercially available, for example some models of the Kay Electronics Corporation, have a number of input channels, which are controlled by a switch. One can thus connect either a tape recorder or a microphone to the machine and select the input that one wants.

Traditional analogue versions of the sound spectrograph record the input signal on a magnetic medium that goes around the edge of a thin drum or disk. The recording head, which is similar to the recording head on a conventional tape recorder, forms a magnetic "image" on the surface of the magnetic recording disk. When the machine is switched to its analysis mode the input signal is replayed repeatedly through a band pass filter whose centre frequency differs continuously, usually in the 80-8000Hz range. At the same time, the output from the filter is fed to a stylus against a rotating drum as a current differing in amplitude according to the energy present in the sound. The stylus moves along the frequency scale of the spectrogram in proportion to the filter centre frequency. The current passing through the stylus burns a trace on a special paper wrapped round the drum of the instrument; the blackness of the paper corresponds to the energy intensity present at that frequency and time. The dark, essentially horizontal, bands on the spectrogram relate to the formants (peaks in the vocal tract response.

There are two types of spectrograms, namely, "narrow band" (made using an analyzing filter with a band width of 45Hz) and "wide band" (made using an analyzing filter with a band width of 300Hz). A wide band spectrogram is more accurate in the time dimension, and may show lines which represent individual glottal pulses (called striations). A narrow band spectrogram is more accurate in the frequency dimension and typically represents individual harmonics on parallel horizontal lines. See Figs. 5.13.4a & b which show wideband and narrowband spectrograms.

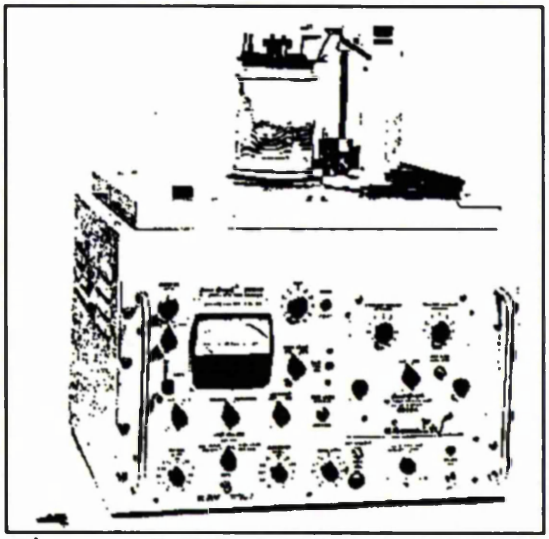


Figure 5.13.3: The Sound spectrograph.
Source: Painter (1979)

In addition to a choice of filter, the spectrograph provides a means of representing intensity as a function of frequency at a given time during an utterance. This is called a **section**. In other words a section refers to the intensity/frequency analysis of a given portion of a speech signal (say the middle of the steady state of a vowel) at a given time.

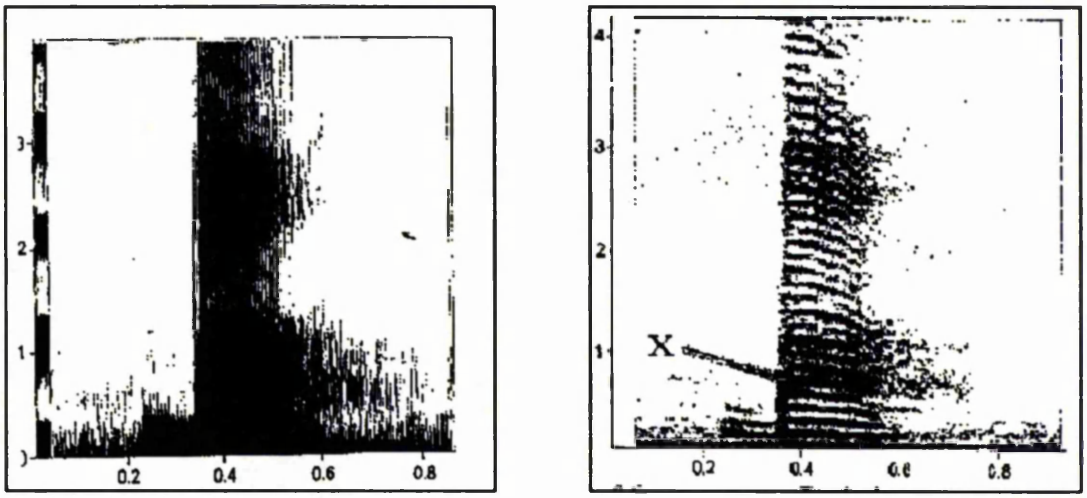



Fig. 5.13.4(a & b). (a) Wideband spectrogram of the sound [ba] and (b) Narrowband spectrogram of the sound [ba] analyzed in (a). The symbol X denotes the fifth harmonic of the fundamental frequency.
Source: Lieberman and Blumstein (1988:56 and 58).

On a narrow band spectrogram, fundamental frequency may be determined by measuring the frequency of the first or higher harmonic at a given time; if the nth harmonic is chosen, its frequency must, of course, be divided by n to give the Fo value. It is usually advantageous to choose a higher harmonic because the higher harmonics are easier to measure and any variations in fundamental frequency are magnified. For low-pitched voices, fundamental frequency may also be determined from broad band spectrograms by determining the time interval between individual striations (the period) and dividing this into 1. The procedure is time consuming and difficult to apply when the fundamental frequency is changing.

5.13.2.2 Computer-Implemented Digital Techniques.

Under this heading come both dedicated machines, such as the Kay digital spectrograph, and systems for a variety of computers. Computer-implemented techniques began to substitute for the traditional spectrograph in the 1970s. The methods are more accurate and can derive information which the traditional spectrograph inherently cannot. With the advent of systems for personal computers, they are becoming ever more widely available.

Although computer-implemented systems may produce three-dimensional spectrograms and two-dimensional sections which look very similar to the traditional ones, the methods used are very different. The signal is first recorded and digitised, that is, converted from a continuously varying electrical signal to a series of numbers representing amplitude values at discrete points in time. The digital representation is stored in electronic memory. Spectral analysis is performed mathematically, using a technique known as the Fast Fourier Transform (FFT). As with the traditional method described above, there is a trade-off between accuracy in the frequency domain and accuracy in the time domain, and both "broadband" and "narrowband" analyses are possible. For further introduction to digital techniques see Liberman and Blumstein (1988).

### 5.13.3 Some Applications of the Technique in Speech Research.

There are acoustic aspects of speech which can be analyzed and subsequently interpreted to give insights into the effects of voice quality. In recent years many investigators have been interested in determining which acoustic properties are crucial to distinctions in phonation types. The intention is to gain an improved understanding of the mechanism involved in production and perception of different phonation types. From the acoustic properties it has been possible to draw conclusions regarding the behaviour of the larynx and its effect on the speech pressure waveform.

Two main types of acoustic analyses of concern here are:

1 Studies of Contrastive Phonation types and
2 Studies of Sounds Produced with Glottalic Airstream Mechanism.

5.13.3.1 Studies of Contrastive Phonation Types.

Fischer-Jørgensen (1967) examined modal (clear) vowels and breathy (murmured) vowels in Gujarati. Ten subjects were recorded on a tape recorder reading several word lists containing three examples of various word pairs containing monosyllabic and disyllabic words spoken in series. The number of examples differed from speaker to speaker. The tape recordings were used for analysis by means of a pitch meter and intensity meter to measure the following parameters.

1 Duration. This was measured on the basis of acoustic curves particularly on the basis of an oscillogram and intensity curve.

2 Fundamental frequency. Frequency was measured at some selected points on a frequancy curve, namely the beginning and end of a vowel.

3 Intensity (amplitude). As a measure of the amplitude the root mean square value was chosen. The amplitude measurements were made on the basis of sections. The section was taken in the relatively steady state part of the vowel (but there may be differences between different parts of the vowel).

Results were presented in the form of tables and they are as follows:

Table 5.13.1: Duration of vowels in monosyllables and disyllables (averaged, in milliseconds).
Source: Fischer-Jørgensen (1967:93).

| Speaker | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of words | | 456 | 180 | 468 | 152 | 216 | 160 | 207 | 72 | 54 | 42 |
| Murmured | | 263 | 250 | 201 | 197 | 248 | 203 | 163 | 299 | 331 | 166 |
| Clear | | 248 | 213 | 174 | 164 | 232 | 179 | 149 | 278 | 309 | 139 |
| Difference | | 15 | 37 | 27 | 33 | 16 | 24 | 14 | 21 | 22 | 17 |
| Increase in % | 6 | 17 | 16 | 20 | 8 | 14 | 11 | 8 | 7 | 19 | |

Table 5.13.2: Fundamental Frequency measurements averaged in milliseconds.
Source: Fischer-Jørgensen (1967:97).

Minimum (Beginning) (Hz).

| Speaker | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Number of words | | 552 | 89 | 91 | 348 | 159 | 100 | 147 | 72 |
| Murmur | | 137 | 114 | 120 | 133 | 133 | 131 | 110 | 129 |
| Clear | | 148 | 119 | 126 | 134 | 136 | 137 | 117 | 140 |
| Difference | | -11 | -5 | -6 | -1 | -3 | -6 | -7 | -11 |
| Lowering in % | 8 | 4 | 4 | 1 | 2 | 5 | 6 | 7 | |

Table 5.13.3: Average differences in amplitude (in dB) between murmured and clear vowels.
Source: Fischer-Jørgensen (1967:101).

| Speaker | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of words | 160 | 215 | 163 | 170 | 94 | 160 | 144 | 72 | 54 | 40 |
| Diff mur-clear | +0.4 | +0.1 | -0.5 | +1.1 | +0.5 | -1.2 | +0.8 | +0.5 | -1.0 | -1.6 |

1 Duration. When duration measurements were compared, breathy vowels were shown to be longer than normal vowels; the difference was statistically significant for all speakers (see Table 5.13.1 which contains duration measurements for vowels in monosyllables and disyllables).

2 A comparison of the averages for fundamental frequency measurement for each recording of the vowel types (for eight subjects) showed that words with breathy vowels have a lower minimum (from 1-11Hz, or 1 to 8 per cent less) than words with clear vowels (cf. Table 5.13.2).

3 Intensity. Measurements of overall intensity showed that there is no consistent difference between breathy and clear vowels. The average differences for the different speakers and recordings which lie between +1.1 and -1.6 dB are given in Table 5.13.3.

Bickley (1982) undertook an investigation of normal ("clear") and breathy vowels acoustically in two languages, !Xóõ (a South African language) and Gujarati (cf. section 5.11.4 for a discussion of her experimental procedures). She used Ladefoged's !Xóõ material. Spectral analysis was made of the steady state portion of vowels of the two languages. For !Xóõ, narrowband and wideband spectrograms were made (cf. Fig. 5.13.5).

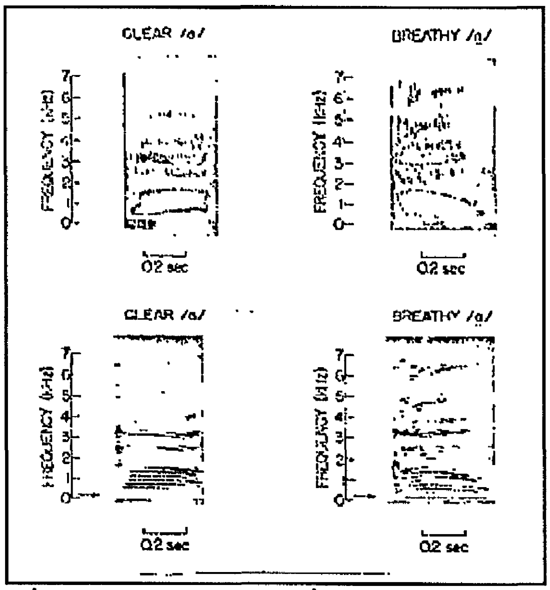



Figure 5.13.5: Wideband (top) and narrowband (bottom) spectrograms of examples of !Xóõ clear (left) and breathy (right) vowel /a/ and /a̲/.

Source: Bickley (1982:75).

Bickley measured the amplitude of the first and second harmonics of the vowels, and summed up her results as follows:

"the amplitude of the first harmonic of the breathy vowels was always greater than the amplitude of the second harmonic. In contrast, the amplitude of the first harmonic in the clear vowels was always less than the amplitude of the second harmonic. Also, the amplitudes of the first harmonics in the breathy vowels were always greater than those in the clear vowels produced with the same vocal effort" (Bickley 1982:74).

See Table 5.13.4 which shows the difference between amplitudes in (dB) in first and second harmonics for breathy and clear vowels in !Xóõ and Table 5.13.5 showing relative amplitude of clear /a/ and breathy /a̤/ for Gujarati). The author did not give the number of tokens recorded. See also Fig. 5.13.6. showing the different waveforms and spectra for the Gujarati vowels.

Table 5.13.4: Difference between amplitudes (in dB) of first and second harmonics for breathy and clear vowels in !Xóõ.

| | Differences in dB | |
|---|---|---|
| Speaker | Breathy | Normal |
| 1 | 13 | 0 |
| 2 | -4 | -3 |
| 3 | 2 | -3 |
| 4 | 5 | -4 |
| 5 | 5 | -9 |
| 6 | 4 | -8 |
| 7 | 11 | 0 |
| 8 | 9 | -2 |
| 9 | 15 | -2 |
| 10 | 10 | 2 |

Another study aiming to determine which acoustic dimensions might be distinctive for phonation type is Kirk et al.'s (1985) study of the three-way phonation type distinction in Jolapa Mazetec. Using spectrographic and speech waveform analysis, they found that the graphic displays were different for the three phonation types.

Table 5.13.5: Relative amplitudes (in dB) of first and second harmonics for breathy (top) and normal (bottom) vowels in Gujarati. Differences are shown at the right. Source: Bickley (1982:73-74).

| | Amplitudes in dB | | |
|---|---|---|---|
| | harmonic first | second | difference |
| bar | 44 | 42 | 2 |
| maro | 46 | 42 | 4 |
| wali | 47 | 42 | 5 |
| bar | 42 | 44 | -2 |
| maro | 43 | 43 | 0 |
| wali | 38 | 44 | -6 |

In Jolapa Mazetec there is a contrast between creaky, breathy and modal voice. Five native speakers all of whom speak the same dialect served as subjects. They recorded several word lists (number of tokens not given) showing contrasts between the different vowel types, but for the purposes of the analysis only three words were used, one each for the different vowel types.

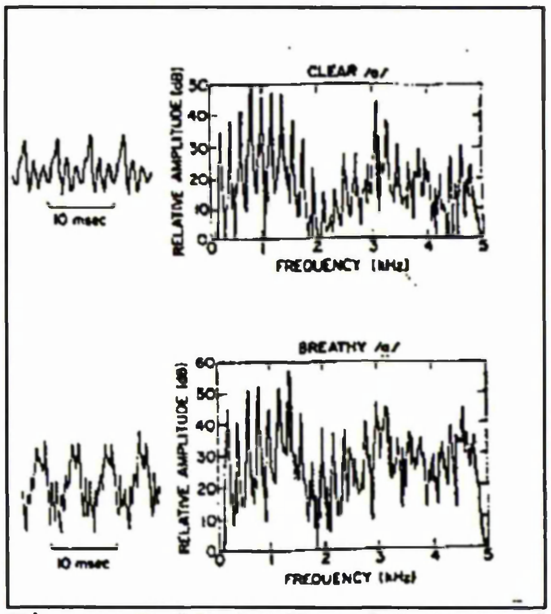



Figure 5.13.6: Waveforms and spectra of a Gujarati clear /a/ (top) and breathy /a̲/ (bottom).
Source: Bickley (1982:73).

Kirk et al. identified and discussed several properties of the spectrographic displays which might be distinctive for these phonation types. The parameters considered were:

1 Formant characteristics (measured on a wide band

spectrogram;

2 Duration (also measured on a wide band spectrogram). The beginning of the vowel was considered to be the first pulse of the vocal folds after the release of the consonants. The end of the vowel was taken to be the last point at which there is energy in two of the formants;

3 Periodicity of the glottal pulses (measured on the speech pressure waveforms);

4 Relative intensity of $F_0$ and $F_1$, (measured from the power spectra obtained from a narrow band spectrogram). They chose as a measure the difference in dB between the intensity of the fundamental and the intensity of the largest harmonic in the first formant.

Comparing the different spectrographic displays illustrating the three phonation types, they note that, with regard to formant characteristics, there are clear, well-defined formants during creaky voice (cf. Fig. 5.13.7a), fairly visible formants during modal voice (cf. Fig. 5.13.7b) and less well defined first formants during breathy voice (cf.Fig. 5.13.7c). In general the formants are in similar places in all three phonation types. However, in creaky voice the first formant sometimes tends to have a slightly higher frequency, a difference which Kirk and his co-workers suggest is associated with raising of the larynx and the consequent shortening of the vocal tract during creaky phonation (cf. Fig. 5.13.7).

Furthermore, a comparison of durations showed that the vowel segments are longer during breathy and creaky phonations than in modal voice. The mean durations for the 5 speakers are 226 msec for creaky vowels, 224 msec for breathy vowels and 174 msec for modal vowels (cf. Kirk et al. 1985:105).

As regards the waveform analysis, a comparison of the speech pressure waveforms for the three phonation types shows that the breathy-voiced vowels are characterized by an onset during which pulses are indiscernible, while modal-voiced vowels show regular pulses and creaky vowels irregularly spaced pulses (cf. Fig. 5.13.8).

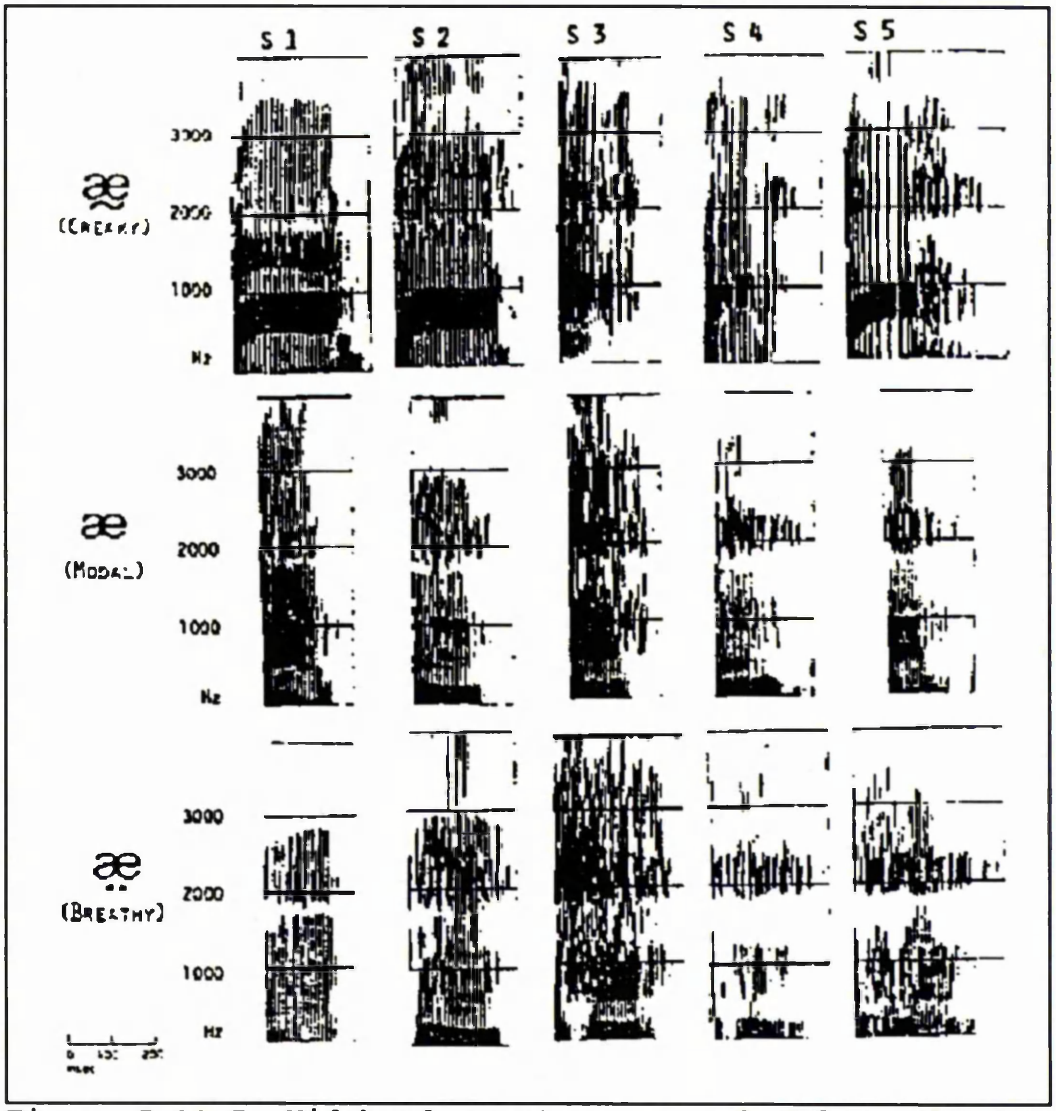



Figure 5.13.7: Wideband spectrograms of Jolapa Mazetec creaky, modal and breathy vowels.
Source: Kirk et al. (1985:106).

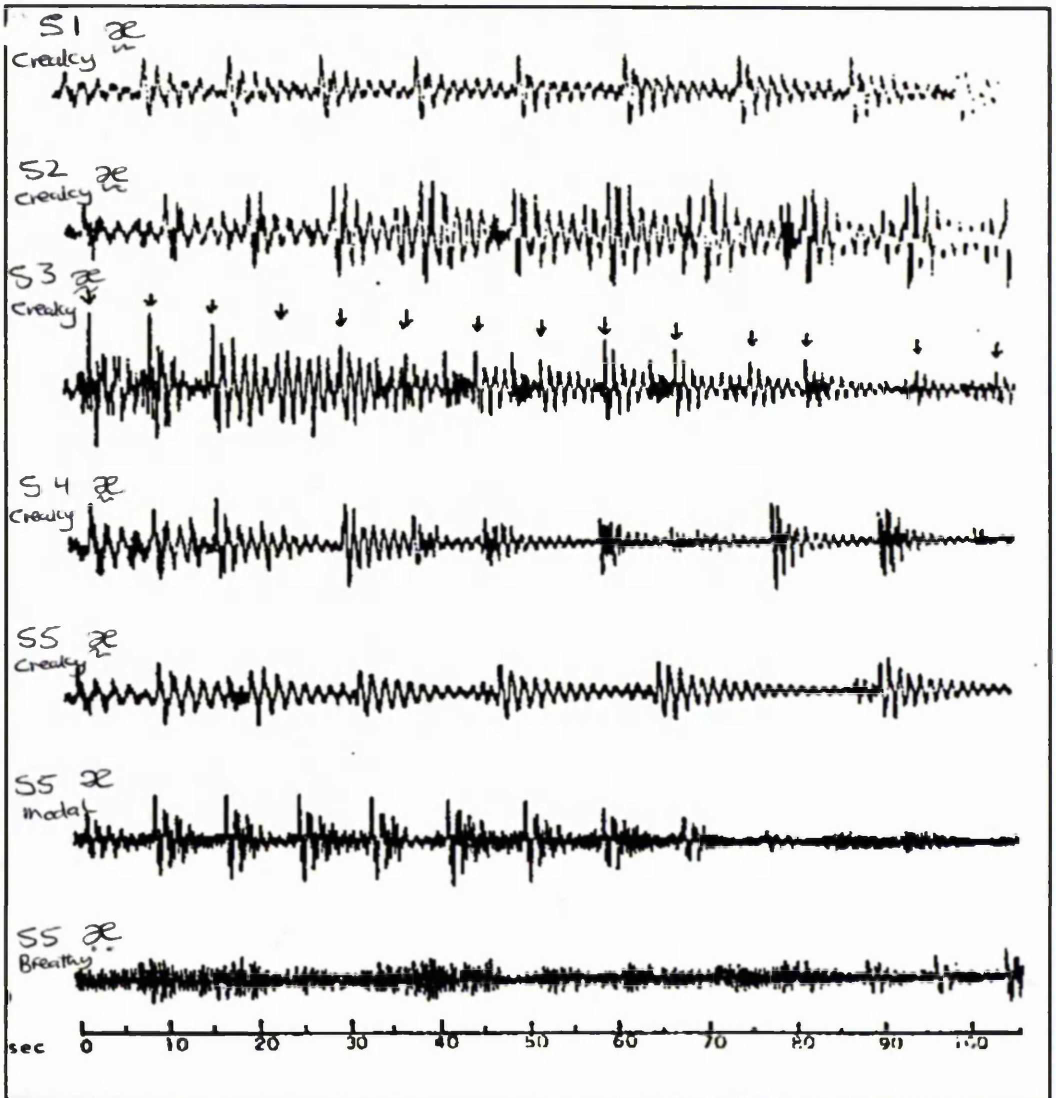



Figure 5.13.8: Waveforms of Jolapa Mazetec creaky, modal and breathy vowels.
Source: Kirk et al. (1985:111).

As for relative intensity of $F_0$ and $F_1$, a comparison between the three phonation types reveals clear differences (cf. Fig. 5.13.9 which shows a display of power spectra for the three phonation types). For the five speakers, Kirk et al. report that:

1 The mean for creaky voice is -17dB with a standard deviation of 3.7 (i.e. the amplitude of the fundamental is 17dB lower than the first formant);
2 The mean for modal voice is -6.6dB with a standard

deviation of 4.4;

3 The mean for breathy voice is +5.2dB with a standard deviation of 3.8.

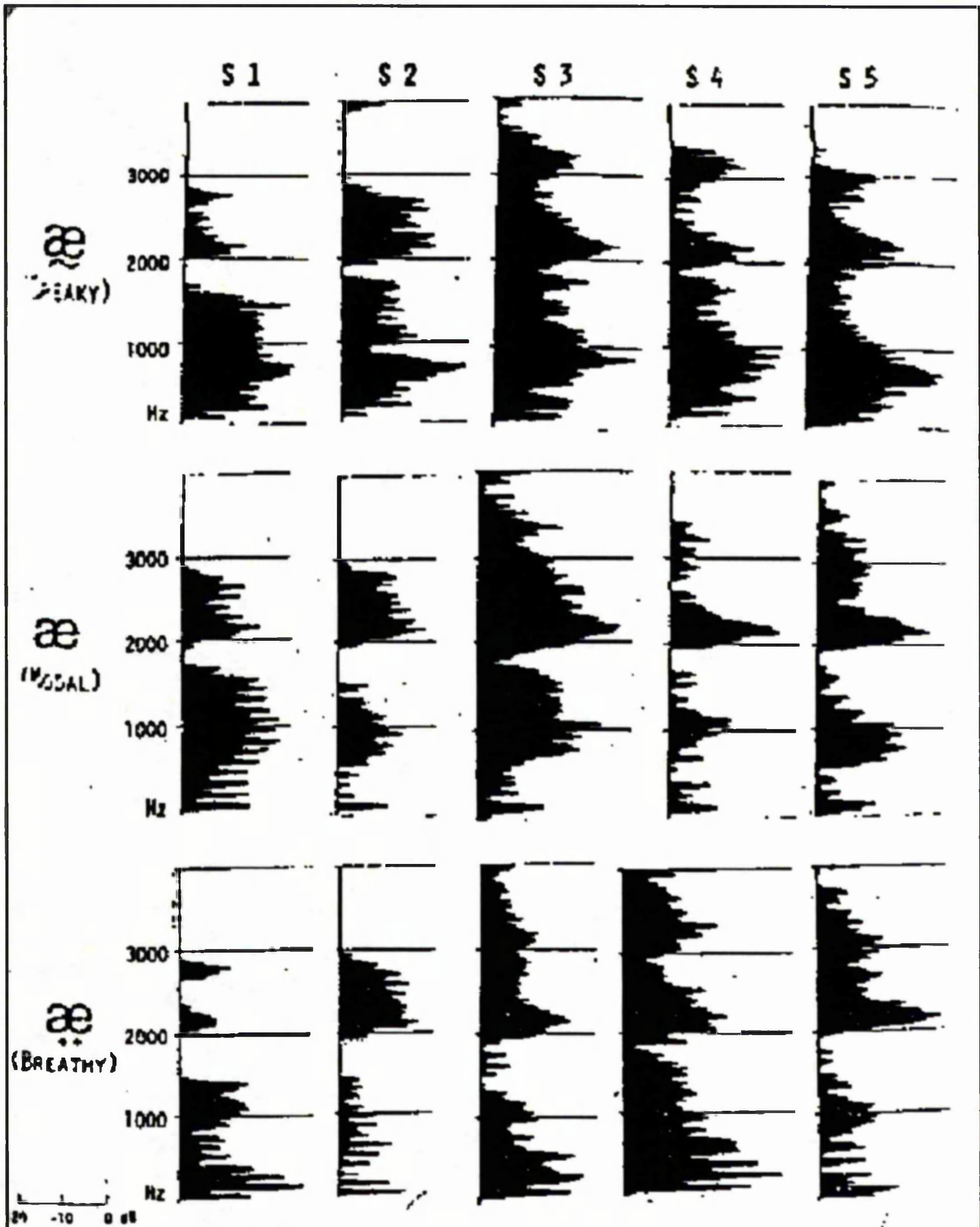



Figure 5.13.9: Spectra of Jolapa Mazetec creaky, modal and breathy vowels.
Source: Kirk et al. (1985:108).

However, it was observed that there is considerable variation from speaker to speaker. Nevertheless, for each speaker on this measure the value for creaky voice is less than that for modal voice, and the value for modal voice is less than that for breathy voice (cf.Fig. 5.13.10) which shows the difference between the amplitude of the fundamental and that of the first formant.

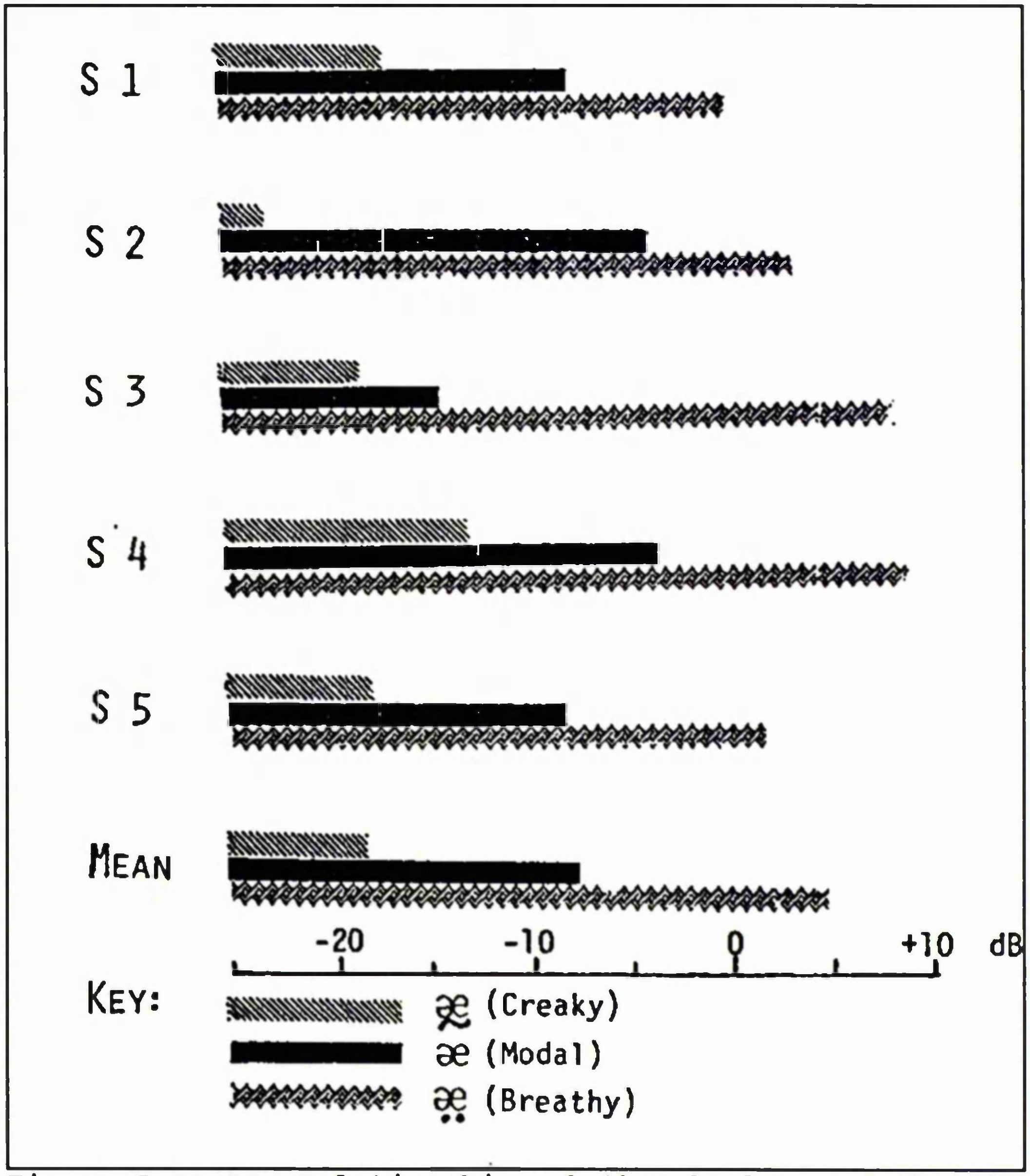



Figure 5.13.10: Relationship of the fundamental to the first formant in Jolapa Mazetec vowels.
Source: Kirk et al. (1985:110).

As regards the relationship between spectrographic properties and laryngeal gestures, Kirk et al. argue that the observed characteristics of creaky voice are due to the fact that when producing creaky voice the vocal tract is much more tensed, with the vocal folds closing more rapidly during each glottal cycle; as a result the vocal tract is excited by sharper pulses that have more energy. The less well-defined formant structure in breathy voice as against modal voice is explained by the fact that, when producing this phonation type, the vocal folds are vibrating more loosely, often not making complete contact along their entire length at any time in the glottal cycle (cf. Ladefoged 1971). As a consequence, there is a greater airflow through the glottis producing a turbulent airflow with a more random frequency component.

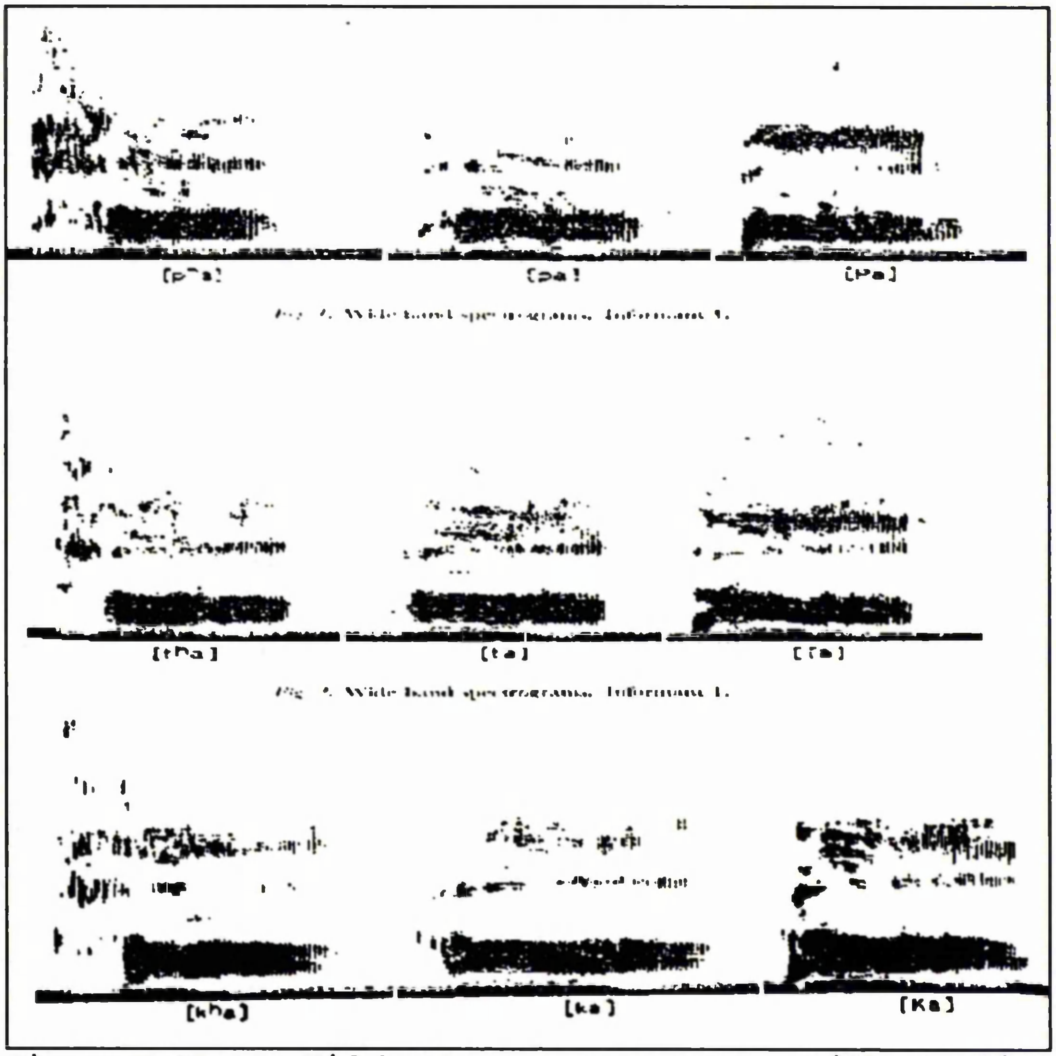


Figure 5.13.11: Wideband spectrograms illustrating differences among the three stop types /P,T,K; p,t,k and ph,th,kh/.
Source: Han et al. (1970:113-4).

Han et al. (1970) investigated the acoustic features related to the three-way manner of differentiation of Korean stop consonants (cf. section 5.5.3 for an explanation of the Korean stops). The examination of the stop series was limited to initial position only. Three native speakers (two males and one female) of the Seoul dialect served as subjects. They recorded over 1,400 word tokens from which wide band spectrograms were made for analysis (cf. Fig. 5.13.11).

The following were examined:

1 The timing of the voice onset (defined as the time interval between the release of the stop and the onset of voicing, VOT for short). Wide band spectrograms were used to determine VOT associated with the three stop types;
2 Quality of the voice onset. This involves such parameters as (1) onset value of fundamental frequency and (2) intensity characteristics of the initial phase of voicing. The measures of the onset value of fundamental frequency following a stop consonant were taken from narrow band spectrograms of single utterances recorded by two of the speakers (one male and the female, cf. Table 5.13.6).

The authors report that all three stop types differ considerably from each other. Their results are summarized as follows:

1 VOT. The time interval between stop release and voice onset averages two to five times longer for aspirated stops than for weak stops. The voice onset time of weak stops averages one and a half to five times longer than that of strong stops (cf. Table 5.13.6).

However, when ranges were compared, it was found that

Table 5.13.6: Voice onset time (in milliseconds).
Source: Han et al. (1970:115).

| Subject | | Range | | | | Range | | | | Range | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ave. | min. | max. | | ave. | min. | max. | | ave. | min. | max. |
| 1 | /ph/ | 129 | 80 | 185 | /th/ | 133 | 85 | 190 | /kh/ | 148 | 95 | 205 |
| | /p/ | 27 | 15 | 45 | /t/ | 33 | 15 | 80 | /k/ | 62 | 40 | 100 |
| | /P/ | 5.3 | 0.0 | 25 | /T/ | 12 | 05 | 25 | /K/ | 20.4 | 12.5 | 35 |
| 2 | /ph/ | 105 | 75 | 140 | /th/ | 107 | 75 | 170 | /kh/ | 136 | 110 | 175 |
| | /p/ | 19.6 | 7.5 | 40 | /t/ | 22.9 | 12.5 | 30 | /k/ | 42.4 | 15 | 72.5 |
| | /P/ | 4.8 | 0.0 | 10 | /T/ | 7.5 | 2.5 | 15 | /K/ | 27.1 | 12.5 | 52.5 |
| 3 | /ph/ | 66.0 | 20 | 95 | /th/ | 73 | 45 | 130 | /kh/ | 71 | 40 | 110 |
| | /p/ | 16.8 | 5 | 32.5 | /t/ | 21 | 10 | 40 | /k/ | 27.2 | 15 | 50 |
| | /P/ | 4.8 | 0 | 10 | /T/ | 5.7 | 2.5 | 15 | /K/ | 15.2 | 7.5 | 27.5 |

Two males (subjects 1 and 2) and one female (subject 3).

weak and strong stops do overlap, as do aspirated and weak stops, but the degree of overlap is much less between weak and aspirated stops than between weak and strong stops. For example, the occurrences of overlap in voice onset time for aspirated and weak stops as spoken by subject 1 were only 2 instances out of a possible 201. In the data for subject 3, the occurrence of overlap between aspirated and weak stops /ph/ and /p/ and between /kh/ and /k/ were 20 out of 161 and 16 out of 118 respectively.

2 Onset value of fundamental frequency. Using the narrow band spectrograms to measure the value of fundamental frequency following the series of stops, Han et al. found that the onset value of fundamental frequency following an aspirated or strong stop is relatively higher on average than that following a weak stop, and that following an aspirated stop seems to be somewhat higher than that following a strong stop (cf. Table 5.13.7).

However, as regards the pattern of development of fundamental frequency associated with each stop type, they observed that,

Table 5.13.7: Onset values of fundamental frequency following a stop consonant (Hz).
Source: Han et al. (1970:117).

| Subject | | Range ave. | min. | max. | | Range ave. | min. | max. | | Range ave. | min. | max. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | /ph/ | 184 | 150.0 | 220.0 | /th/ | 205 | 175.0 | 233.0 | /kh/ | 201 | 166.0 | 230.0 |
| | /p/ | 144 | 130.0 | 170.0 | /t/ | 161 | 130.0 | 173.0 | /k/ | 162 | 140.0 | 170.0 |
| | /P/ | 178 | 145.0 | 215.0 | /T/ | 191 | 177.0 | 225.0 | /K/ | 188 | 170.0 | 205.0 |
| 3 | /ph/ | 341 | 317.5 | 368.7 | /th/ | 334 | 307.5 | 367.5 | /kh/ | 343 | 310.0 | 389.0 |
| | /p/ | 266 | 250.0 | 292.0 | /t/ | 312 | 292.5 | 327.5 | /k/ | 309 | 292.5 | 327.5 |
| | /P/ | 308 | 277.5 | 322.5 | /T/ | 345 | 325.0 | 370.0 | /K/ | 337 | 320.0 | 355.0 |

"After weak stops the fundamental frequency begins at a relatively low level and then rises to a relative peak in 5-10 centiseconds. On the other hand, the fundamental frequency following a strong or aspirated stop begins at a relatively high value and stays that way or begins to fall within the first 5-10 centiseconds" (Han et al. 1970:116).

3 Intensity characteristics. A comparison of the oscillograms (waveforms) of vowel onsets associated with each stop type indicates a number of differences in the intensity build-up after the onset of voicing. Following a weak stop, the intensity build-up after the onset of voicing is "relatively slow" averaging about 4 centiseconds or 3-6 cycles. Following a strong stop, the build-up is relatively short, averaging about 0.3 centiseconds or 1-2 cycles. Following an aspirated stop, the intensity build-up is intermediate between strong and weak stop.

On the spectrograms formants appear weakened during the onset of voicing following a weak stop. Following a strong stop, the voice onset appears very sharp and the harmonic partials appear relatively undamped. The voice onset following an unaspirated stop shows an intermediate quality between weak and strong stops; the harmonic partials are weaker than those following the strong stop but stronger than those following the weak stop (cf. Fig 5.13.11).

In a similar study, Hardcastle (1973) examined the acoustic and aerodynamic aspects associated with the 3 types of Korean stops (cf. section 5.12.3 for a discussion on methods). The acoustic signal was recorded on a tape recorder using a microphone. To obtain a more accurate record of the acoustic signal, a permanent tracing of the waveform was provided by a Siemens Oscillomink. From the acoustic data, measurements were made of the following parameters:

1 VOT (duration of aspiration);
2 Frequency of glottal vibrations at the onset of voicing immediately following the initial stop.

The results show a clear difference in VOT for each of the stop types in any of the given places of articulation, and are summarized as follows:

1 The VOTs associated with weak stops are usually about 3 to 5 times as long as those for strong stops. The aspirated stops average about 2 to 3.5 times as long as the weak stops (cf. Table 5.13.8). This also agrees with the observations of Han et al. (1970) above, although they observed a certain overlap in the VOT measurements, particularly between weak and aspirated stops. In the present study, Hardcastle did not observe such an overlap; in his view this is probably due to the fact that fewer tokens were used in his study.
2 A comparison of duration measures of the initial glottal cycle following the stops, obtained from the oscillograms, clearly shows that there are differences between the stop types. After weak stops the glottal cycle was always longer than that following strong and aspirated stops. The glottal cycle following aspirated

stops seemed in general slightly longer than that following strong stop but this difference was usually extremely slight (cf. Table 5.13.9).

Table 5.13.8: Vowel onset times (msec).
Source: Hardcastle (1973:265).

| | Range Minimum | Maximum | Mean |
|---|---|---|---|
| /P/ | 4.5 | 12.0 | 7.6 |
| /p/ | 24.0 | 61.0 | 37.0 |
| /ph/ | 65.5 | 111.0 | 83.0 |
| /T/ | 3.0 | 8.7 | 5.4 |
| /t/ | 13.0 | 49.5 | 22.7 |
| /th/ | 55.0 | 98.0 | 80.1 |
| /K/ | 9.7 | 21.2 | 15.9 |
| /k/ | 43.0 | 70.5 | 51.5 |
| /kh/ | 85.5 | 130.0 | 103.0 |

Table 5.13.9: Duration of the first full glottal cycle of vowel (msec) following the plosive release.
Source: Hardcastle (1973:267).

| | Vowel -/e/ | | | Vowel -/u/ | | |
|---|---|---|---|---|---|---|
| | Range | | | Range | | |
| | Min | Max | Mean | Min | Max | Mean |
| /P/ | 5.0 | 5.2 | 5.1 | 4.7 | 5.0 | 4.9 |
| /p/ | 5.9 | 6.0 | 6.0 | 5.5 | 6.2 | 5.8 |
| /ph/ | 4.9 | 5.5 | 5.2 | 4.6 | 6.0 | 5.0 |
| /T/ | 4.9 | 5.2 | 5.1 | 4.6 | 4.7 | 4.7 |
| /t/ | 5.7 | 6.2 | 6.0 | 5.0 | 6.0 | 5.6 |
| /th/ | 5.4 | 5.7 | 5.5 | 4.7 | 5.0 | 4.8 |
| /K/ | 4.9 | 5.1 | 5.1 | 4.5 | 4.9 | 4.6 |
| /k/ | 5.4 | 6.0 | 5.8 | 5.6 | 5.7 | 5.7 |
| /kh/ | 5.2 | 5.5 | 5.3 | 4.6 | 4.9 | 4.7 |

Another observed difference in the waveforms associated with the three stops lies in the acoustic quality of the onset of the vowel immediately following the stop (cf. Fig. 5.13.12). The qualitative differences in the vocal waveform after the three stop types are quite clear. For example, the double-peak configuration which characterizes the vowel onset following the strong and the aspirated stops does not occur in the vowel following the weak stops until the sixth or the seventh cycle. Hardcastle also reported that spectrograms made of the same tokens used in this study showed clearly that the formant structure was much sharper and the harmonic partials better defined following strong and aspirated stops than following the weak stop (he did not give any example of his spectrograms).

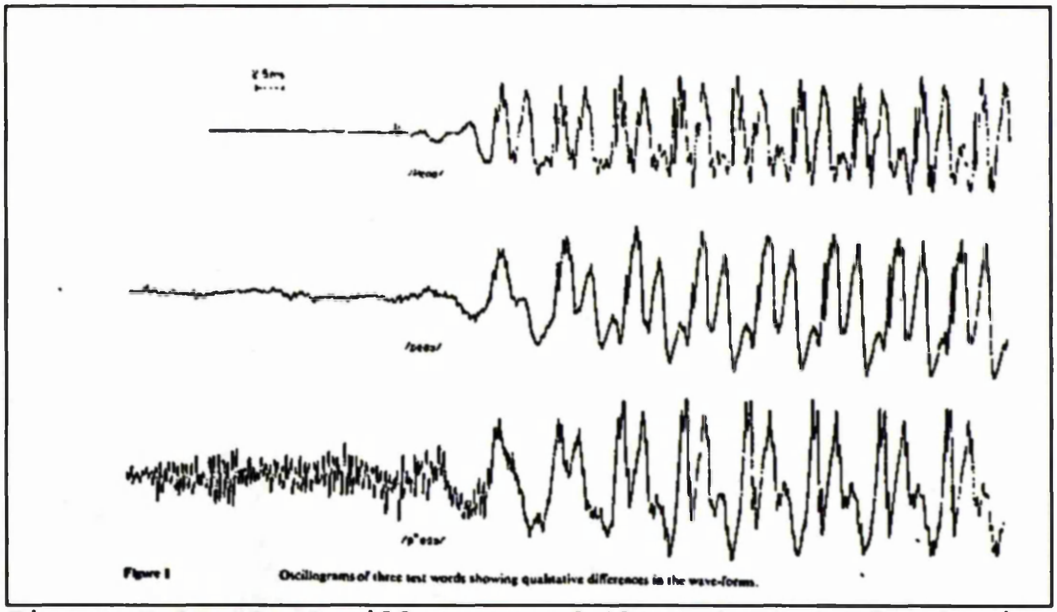


Figure 5.13.12: Oscillograms of three test words showing qualitative differences in the waveforms.
Source: Hardcastle (1973:268).

Kagaya and Hirose (1975) investigated the Hindi stop consonants (cf. section 5.5.3 for an explanation of these stops) using fibreoptics, electromyograpic and acoustic analysis (cf. section 5.5.3 and 5.10.3 for detailed discussions on the first two techniques). The aim of the study was to specify the properties of the Hindi stops. A 44 year old male native speaker of Hindi served as the subject. The acoustic analysis made use of material from two recording sessions. In the first recording the speech signals were recorded (simultaneously) during the fibreoptic experiment and this was used for detailed acoustic analysis (cf. section 5.5.3 for detailed discussion on the recorded material and procedures). Secondly, for supplementary data, different utterance types were recorded separately. In this session nonsense syllables in the forms of /Ci/ and /iCi/, where /C/ stands for one of the dental stops, were uttered five times in isolation. All speech signals were subjected to analysis on spectrograms and oscillograms.

The following parameters were measured:

1 Voice onset time (VOT) of each consonant was measured on the spectrograms with an accuracy of 10msec;
2 Fundamental periods were measured on oscillograms. Measurements were made at the portion immediately before the implosion in all four types, just after the explosion in the two voiced types and at the voice onset in the two voiceless types. For the two aspirated types, an additional measurement was made at the moment when the glottis closed completely after the articulatory release. Fundamental frequency was then obtained by averaging three fundamental periods near the moments mentioned above;
3 Articulatory closure period and duration of aspiration. These were measured on the oscillogram with an accuracy of 5msec;
4 Relative intensity of aspiration noise was compared for the voiced and the voiceless aspirated types by visual observation of the spectrogram;
5 The durations of the fundamental frequency transient portions after the articulatory explosion were also compared with each other by visual observation of the spectrogram.

A summary of their results is as follows:

1 VOT. The results show that VOT for the voiceless unaspirated type is about 10msec on average and that

for the voiceless aspirated type is about 70msec on average. In the voiced types, the vocal folds' vibration is observed through the articulatory closure period. According to the authors, these results are comparable to those reported by Lisker and Abramson (1964) and by Dixit (1975);

2 Fundamental frequency. The results show that fundamental frequency just before the implosion is almost the same for the four types. For aspirated types, fundamental frequency at the moment when the glottis completely closes after the explosion is always higher for the voiceless type than for the voiced counterpart. Also, for unaspirated types, fundamental frequency near the voice onset is always higher for the voiceless type than in the voiced counterpart. For the voiced aspirated type, it is noted that fundamental frequency near the explosion is very low but becomes higher when the glottis closes completely;

3 Closure period. The results show that the closure period for the voiceless unaspirated type is the longest, those for the voiced aspirated and the voiceless aspirated types are the shortest and that for the voiced unaspirated type is intermediate. Duration of aspiration of the voiced aspirated type is almost the same as that of the voiceless aspirated (cf. Table 5.13.10);

4 Relative intensity of aspiration. The results show that the intensity is stronger for the voiceless aspirated type than for the voiced aspirated type;

5 The durations of the fundamental transient portions after the articulatory explosion show no marked difference among the four types (cf. Table 5.13.10).

Ladefoged (1977) has argued, using spectrographic analysis, that types of breathy (murmured) voice which occur contrastively in different languages do not completely

Table 5.13.10: Acoustic Characteristics of Hindi stops.
Source: Kagaya and Hirose (1975:37).

| | | vd. avg. | unasp. Range | vl. avg. | unasp. Range | vd. avg. | asp. Range | vl. avg. | asp. Range |
|---|---|---|---|---|---|---|---|---|---|
| 1 | VOT. | V.T | | +10 | 0/+20 | V.T | | +70 | +50 to +110 |
| 2 | Cl Period (in msec.) | 100 | 80/130 | 140 | 110/170 | 80 | 50/110 | 90 | 70/100 |
| 3 | Dur of Asp. (in msec.). | | | | | 70 | 40/80 | 60 | 40/80 |
| 4 | Rel Inten of Asp. | | | | | weak | | strong | |
| 5 | $F_0$ (in Hz). Implosion | 175 | 166/200 | 169 | 160/182 | 166 | 160/174 | 166 | 154/182 |
| | Release | 154 | 138/174 | | | 120 | 100/133 | | |
| | Voice Onset | | | 188 | 160/222 | | | 178 | 166/190 |
| | Closed Glottis After Release. | | | | | 165 | 148/182 | 179 | 166/190 |

| | | | |
|---|---|---|---|
| V.T: | voice through | Cl: | closed |
| +: | voicing lag | Rel: | Relative |
| Vd: | voiced | Inten: | intensity |
| Vl: | voiceless | Dur: | duration |
| Asp: | aspiration | $F_0$: | fundamental frequency |

intersect. In other words, although breathy voice may contrast linguistically with normal voice, it is not wholly true to say that "breathy voice" is phonetically the same in all languages (cf. also Ladegoged 1984). The languages which were examined in this study were Igbo, Hindi, Gujarati, Marathi and Javanese.

The spectrograms he made for all the above languages were used to examined the parameters:

1 duration and
2 voicing characteristics.

As regards Igbo two speakers (one male and one female) acted as subjects. They read four words, two representing each phonation type. For Hindi, only one female speaker was recorded. She read four words, two each from the two phonation types.

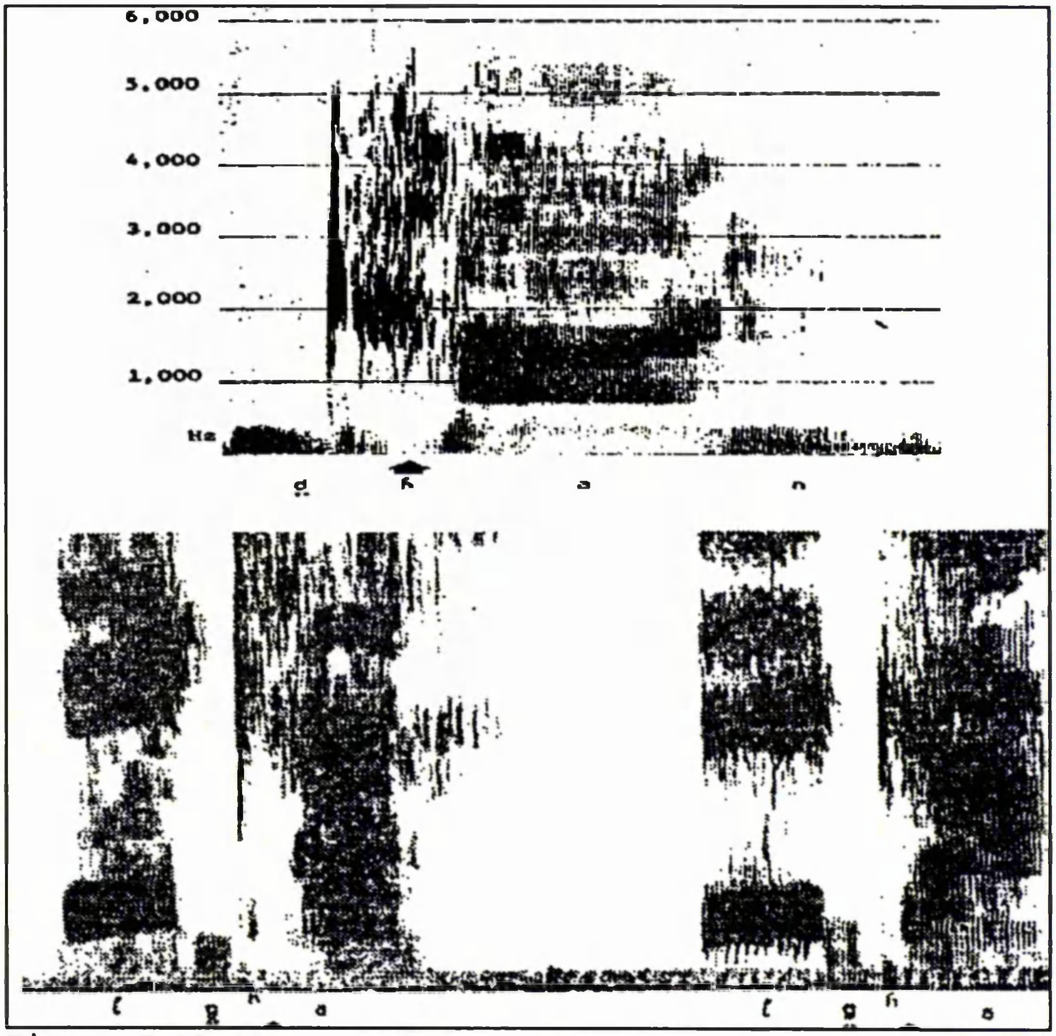



Figure 5.13.13:
(a) Spectrogram illustrating a breathy aspirated plosive in Hindi and
(b) Spectrograms illustrating breathy aspirated plosives in Oweri Igbo.
Source: Ladefoged et al. (1976), taken from Ladefoged (1977:33-34).

Comparison of the spectrographic displays for Hindi and Igbo tokens showed that Hindi murmured voice seems to be more breathy and less voiced, with a longer release duration than Igbo. On the spectrogram this is characterized by a voicing component which is less visible, much random fricative energy in the upper part of the

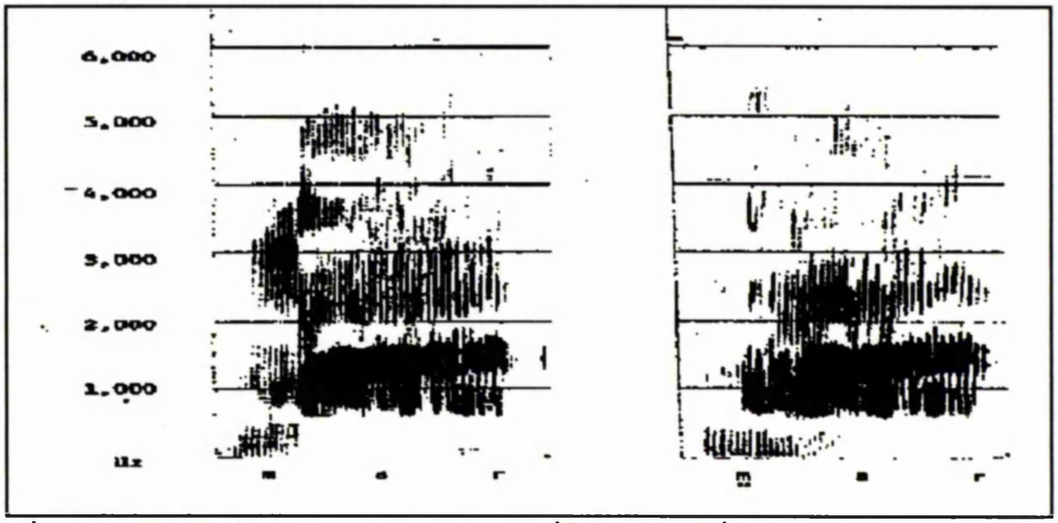



Figure 5.13.14: Spectrogram illustrating the contrast between voiced and murmured nasals in Marathi, and

Source: Ladefoged (1977:36).

spectrogram and a considerably longer murmured release - about 60cm (in Igbo the minimum release lasts 30cm) (cf. Fig. 5.13.13a-b). Two dots below a symbol indicate breathy voice.

Apart from the contrast between breathy and voiced oral stops, Marathi shows contrast between breathy and voiced nasals. Two words were recorded, one illustrating each voice quality (the number of subjects was not given). Ladefoged compared the voicing characteristics of these two phonation types. He notes from the spectrograms that the vertical striations corresponding to the vibrations of the vocal folds are clearly visible during the murmured nasals but less so in the voiced ones (cf. Fig. 5.13.14). He also suggested that the oral stops in Marathi have heavier voicing than those in Hindi.

As for Gujarati, four words were recorded (the number of subjects was not given) showing the contrast between voiced and murmured vowels. A comparison of the two phonation types revealed that murmured vowels contain very substantial vibrations of the vocal folds. The vertical striations corresponding to the vocal fold vibrations are

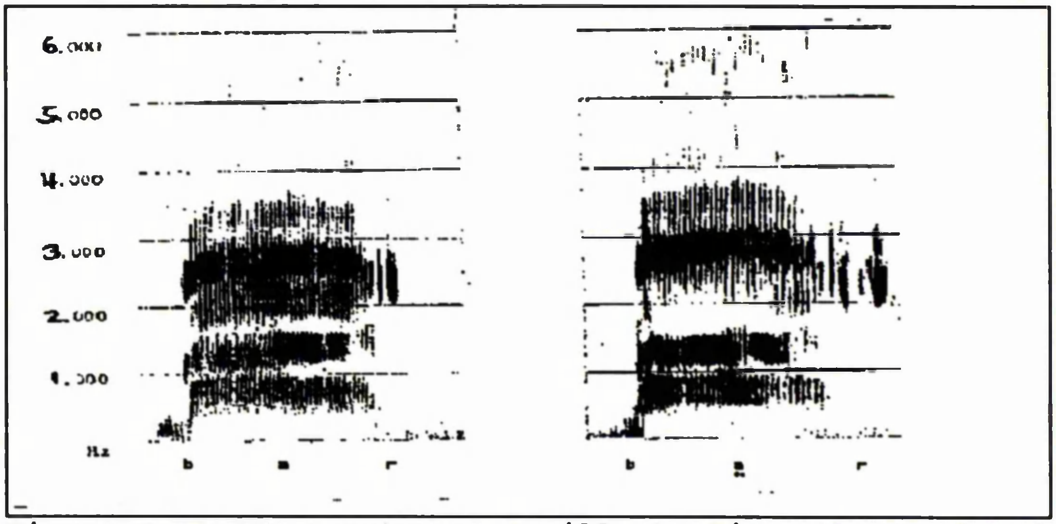


Figure 5.13.15: Spectrograms illustrating the contrast between voiced and breathy (murmured) vowels in Gujarari. Source: Ladefoged (1977:37).

clearly visible on the spectrogram. They differ from the regularly voiced vowels in that the murmured vibrations of the vocal folds do not produce so much energy at the higher formant frequencies (cf. Fig. 5.13.15).

The next language investigated was Javanese. In Javanese there is a contrast between two series of voiceless stops, one of which (written b, d, etc.) has murmured release. Three minimal pairs (6 words) were recorded (the number of subjects was not given). Ladefoged observed the spectrograms and notes that both stops lack vibrating vocal folds during the closure, and the main difference between them is in the quality of the adjacent vowels (cf. Fig. 5.13.16). It can be seen that the first formant frequencies of the vowels following the breathy stops are much lower than those following the voiceless stops. As regards closure duration, both stops seem to be equal.

A comparison between the languages shows that Marathi breathy voice seems to involve heavier voicing (on the spectrograms, the voicing component is clearly visible) than Igbo, Hindi, Gujarati, and Javanese.

Huffman (1985) reports an investigation on the phonetic characteristics of phonation types in Hmong (a South-East Asian language). Hmong uses breathy, creaky (Huffman referred to creaky phonation type as "checked") and normal phonation contrastively. She compared breathy and "checked" tones with normal tones of similar pitch level, range and contour.

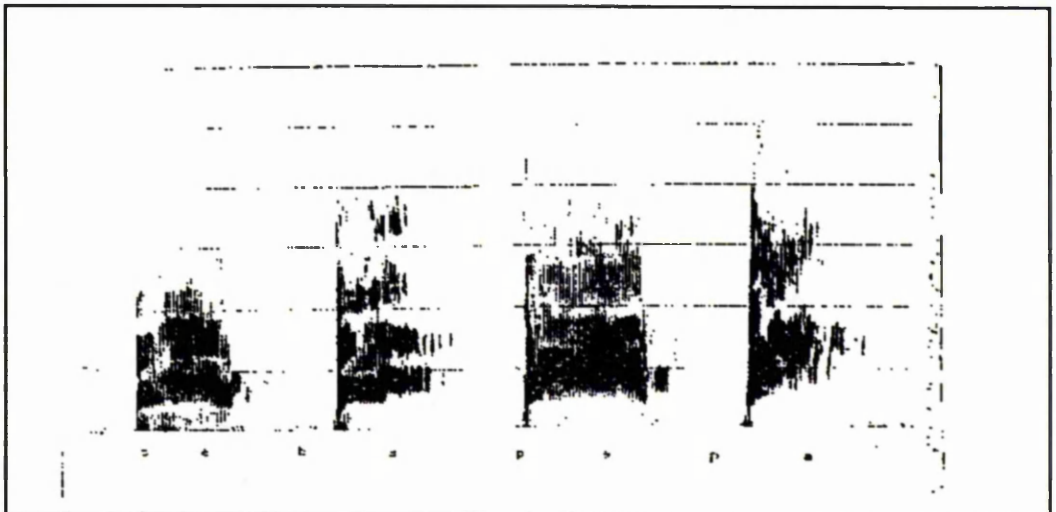


Figure 5.13.16: Spectrograms illustrating contrasting bilabial stops in Javanese, /b/ breathy and /p/ voiced. Source: Ladefoged (1977:39).

Giving a brief summary of the various descriptions of the language, Huffman writes:

> "Tones in Hmong have both a particular pitch and a characteristic voice quality, and five of the seven tones - high, rising, mid, low, falling - are reportedly produced with normal voice. Of the remaining two tones, one is described as low, produced with what Lyman (1974) calls "voiced aspirated" or "breathiness". Smalley (1976) similarly characterizes this tone as breathy, and speculates that this quality is "possibly caused by an enlarged laryngeal cavity and doubtless by special configuration of the vocal folds" (p.100). The other tone is said to be slightly falling, with a reported rising variant which, Lyman notes, occurs in utterance final position and very careful speech. Only falling tokens of this tone were observed in the present study. This seventh tone is characterized by Lyman as

> having a quality of "glottalization" or "creaky" voice (p.38). Smalley, on the other hand, attributes no special voice quality to this tone; rather, he describes it as shortened and "terminated by a glottal stop" (Smalley1976:100). As will be discussed below, Hmong data collected for the present study support Smalley's description; i.e. this seventh tone does not seem to involve a phonation contrast. We will refer to this tone as the 'checked tone'" (Huffman 1985:5).

To quantify the acoustic differences between these phonation types some properties of the speech waveform which might serve to distinguish between phonation types were investigated. Wide band spectrograms were used to determine voicing characteristics in the different vowel types. Narrow band spectrograms were used for pitch measurements. Power spectra, taken during the steady state portions identified on the wideband spectrograms, were used to gain insight into formant structure (cf. section 5.11.3 for the list of subjects and tokens recorded).

Discussing the procedure by which she arrived at her measurements, Huffman writes:

> "In measuring duration from the wideband spectrograms, the beginning of the vowel was taken to be the moment of voice onset after release of the (unaspirated) stops. The end of the vowel was judged as the last point at which there was energy in two of the first three formants. To ascertain pitch (fundamental frequency) from the narrowband spectrograms, measurements were made at onset, midpoint, and offset of the highest well-defined harmonic (usually the fourth or the sixth) for each vowel token. Fundamental frequency was then calculated from these values" (Huffman 1985:8).

Her results are summarized as follows:

1 Examination of the wideband spectrograms reveals that checked tone syllables show final "glottalization". The first part of the vowel usually begins with normal

voice quality, the end of the vowel being characterized by low frequency, often with irregular taps of the vocal folds as they come together for a glottal stop. On the spectrogram it is shown by irregularly spaced voicing striations (she did not provide any spectrograms to illustrate her results);

2 As regards duration the results indicate that creaky vowels are shorter than normal (low, falling) vowels, and that breathy vowels are shorter than normal vowels (cf. Fig. 5.11.9);

3 For fundamental frequency, the results showed considerable variation between speakers for all the vowel types studied. However, individual onset, offset or midpoint values of the vowels types studied are sometimes very similar (cf. Fig. 5.13.17).

Ladefoged (1983), in an article entitled <u>The Linguistic Use of Different Phonation Types</u>, investigated several languages which have contrastive phonation between modal, creaky and breathy voice. Using Linear Predictive Coding (LPC) spectral analysis of normal audio recordings, Ladefoged reported that measures of amplitude of some higher spectral component in relation to the amplitude of the fundamental was a reliable acoustic measure which will distinguish between contrastive phonation types (cf. Bickley 1982, discussed above). To illustrate this fact, Ladefoged considered the language !Xóõ. This language contrasts between voiced, murmured and creaky voice vowels. Recordings were made of ten native speakers saying six words. These recordings were then digitized and stored on a computer for analysis. The sampled waveforms were analyzed along the following parameters:

1 Formant characteristics.

2 Characteristic pattern of the waveforms.

As a means of quantifying the phonation type of the vowels,

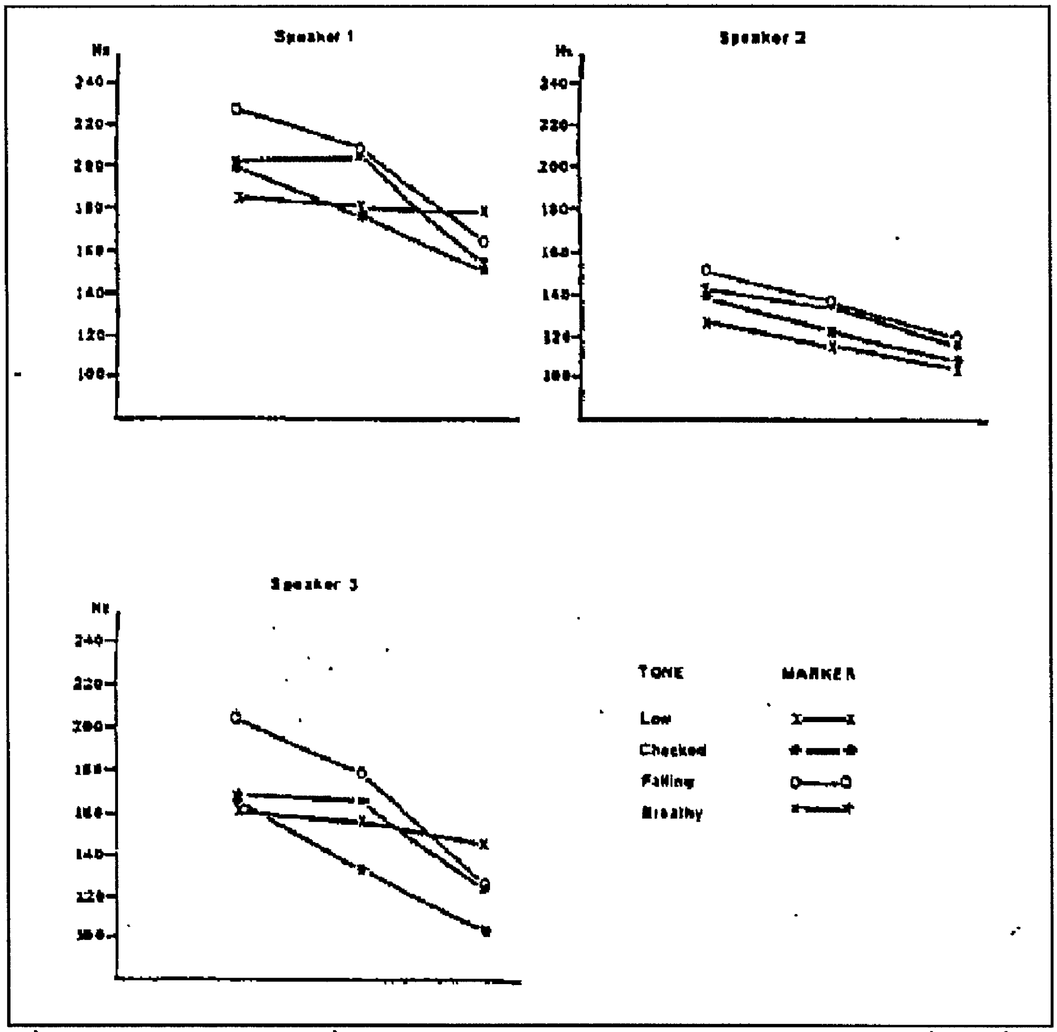



Figure 5.13.17: Pitch contours measured at onset, midpoint and offset, averaged over six tokens per tone, for each speaker.
Source: Huffman (1985:12).

the difference in dB in the spectra (of the vowels) between the amplitude of the largest harmonic in the first formant and the amplitude of the fundamental was considered. The results show that the difference in intensity is much greater for modal voice than it is for breathy voice. Ladefoged remarked,

> "the difference between the intensity of the first formant and the intensity of the fundamental is a much more useful measure of the differences in voice quality. For all ten speakers, on all occasions, this measure was

greater for the voiced sounds than for the corresponding murmured ones. It is reliable and, by any statistic, a highly significant measure of the phonemic differences" (Ladefoged 1983:357).

On the other hand, the murmured vowel has more irregular energy in higher frequencies, with a slightly less falling spectrum than the voiced vowels. Creaky voice shows a great

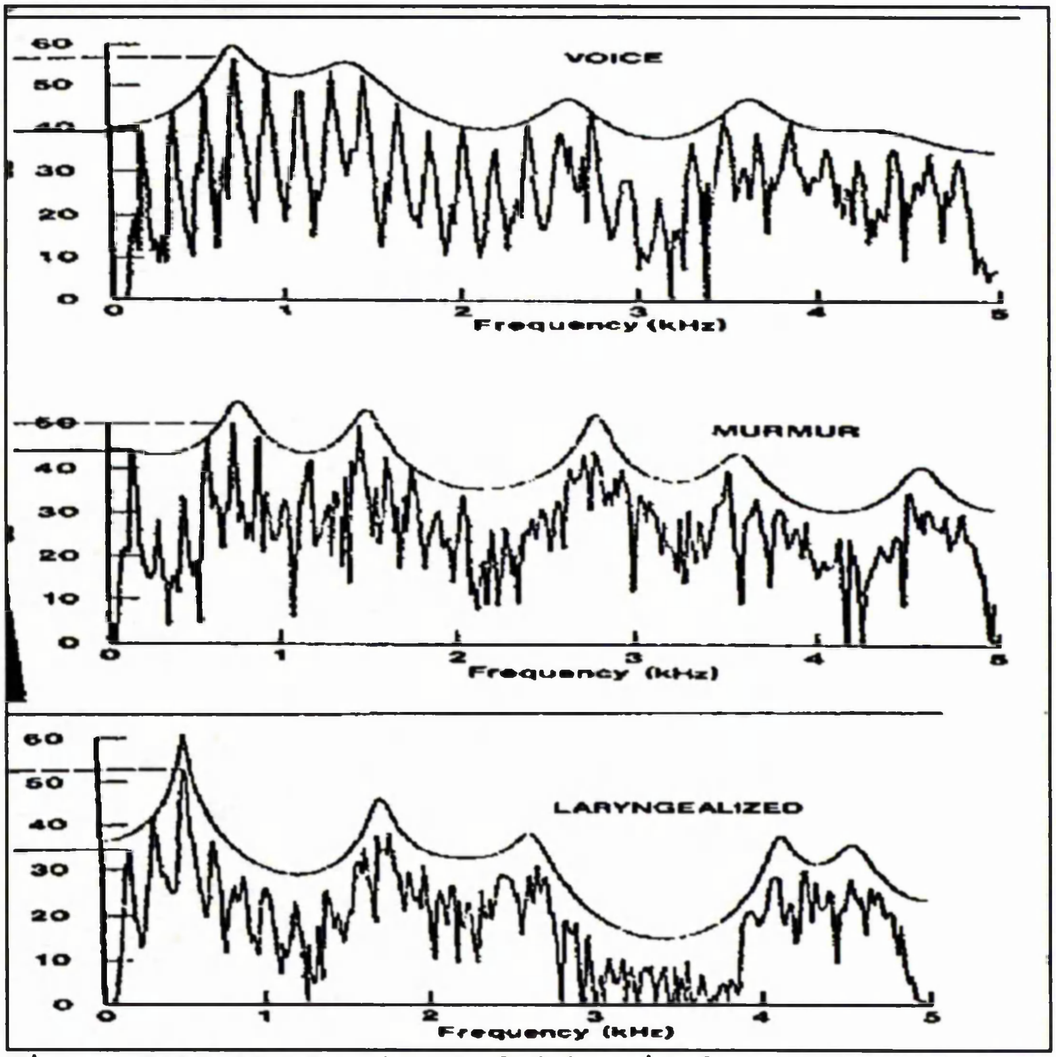



Figure 5.13.18: Spectrum of (a) voiced,
(b) breathy and
(c) laryngealized vowels in !Xóo.
Source: Ladefoged (1983:356).

difference between the amplitude of the first formant and the amplitude of the fundamental (cf. Fig. 5.13.18).

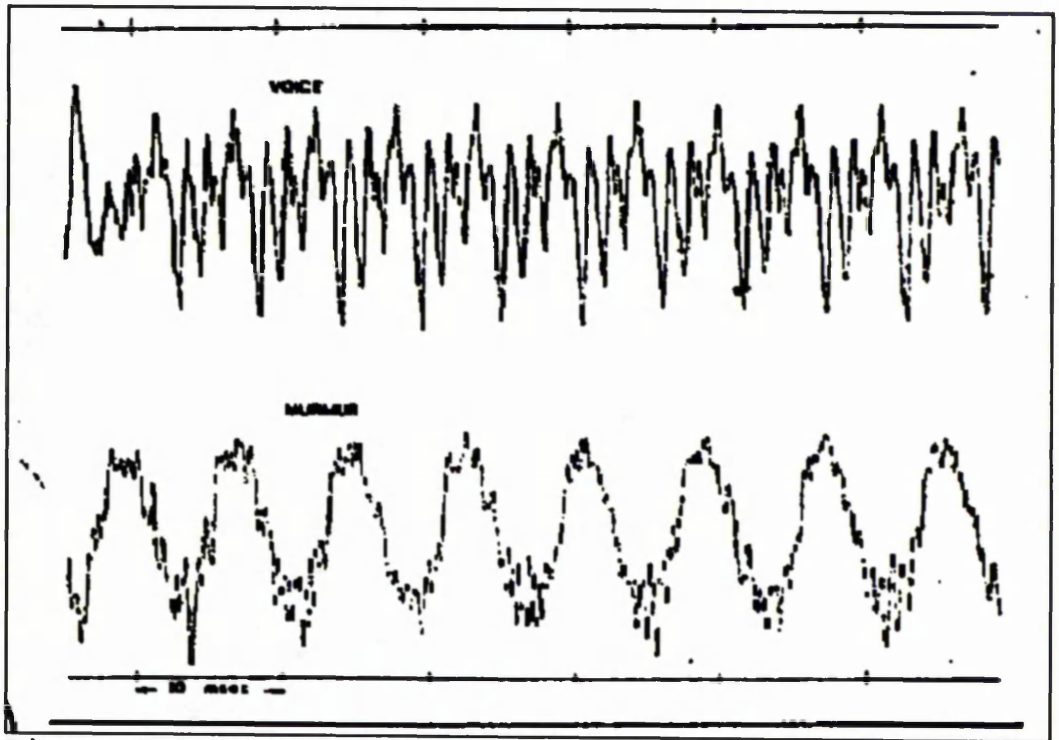


Figure 5.13.19: Parts of the waveforms near the midpoints of the vowels in the !Xóõ /aa/ and /!a̲o/.
Source: Ladefoged (1983:355).

As regards the voicing pattern of the waveforms (cf. Fig. 5.13.19), Ladefoged observed that,

> "The voiced vowel in the upper part of the figure has sharp regular voicing pulses, with the first formant frequency clearly evident in the damped exponent part of the waveform. The waveform of the murmured vowel in the lower part of the picture looks much more like a sine wave at the fundamental frequency, with additional components corresponding to fairly high frequencies. There is very little evidence of the first formant in the lower waveform. It is also clear that murmured vowel has a lower pitch" (Ladefoged 1983:354).

For !Xóõ, the study shows that the difference in voicing pattern and the difference in intensity between the fundamental and the first formant are a fairly reliable cues of the breathy/normal phonation contrast.

#### 5.13.3.2 Studies of Sounds Produced with Glottalic Airstream Mechanism.

Lindau (1984) compared so-called implosives and ejective stops acoustically in a number of West African languages, including Hausa. The others were Degema, Kalabari, Okrika, Bumo and also Navaho. She carried out the acoustic analysis using a computer system displaying speech waveforms (cf. section 6.3 for detailed discussion). The glottalic consonants were placed in an intervocalic position. Spectral analysis was carried out on the first 50ms of the closure part of the implosives in Bumo and Hausa. A comparison of the two languages shows a difference in the formant structure. Bumo implosives exhibit a clear formant structure while Hausa implosives show no clear formant structure. Lindau attributes this to inefficient vocal fold closure in Hausa (cf. Fig. 5.13.20).

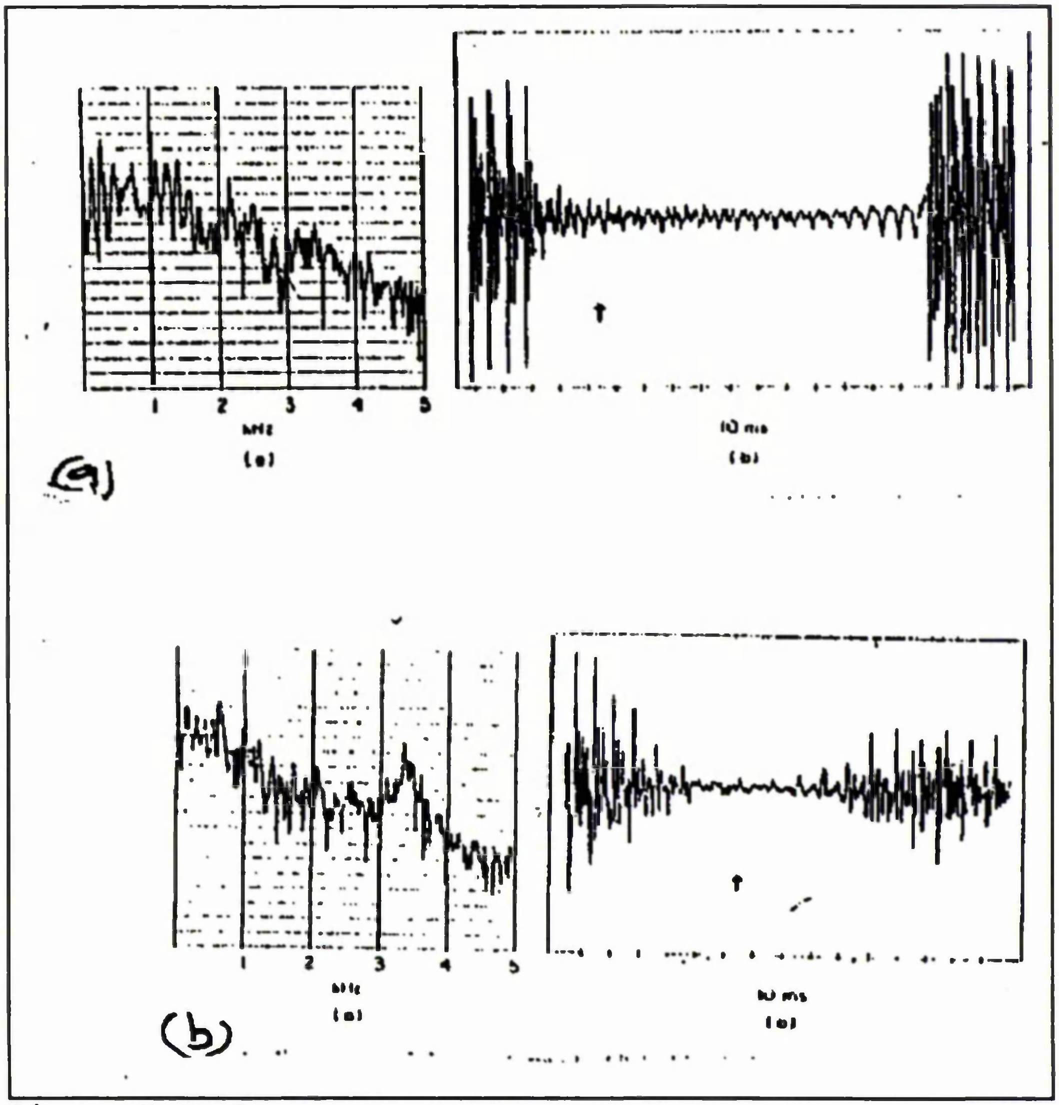



Figure 5.13.20:
(a) Spectrum and waveform of intervocalic bilabial in Bumo and
(b) spectrum and waveform of intervocalic bilabial in Hausa.
Source: Lindau (1984:151-2).

Nihalani (1986) also provided some acoustic data based on spectrograms showing the characteristic properties of Sindhi (cf. section 5.12.3 for the numbers of subjects and tokens recorded for Sindhi), Kalabari and Hausa (for the two last languages, the author did not give the numbers of subjects and tokens recorded; cf. Fig. 5.13.21a-c for those given as examples).

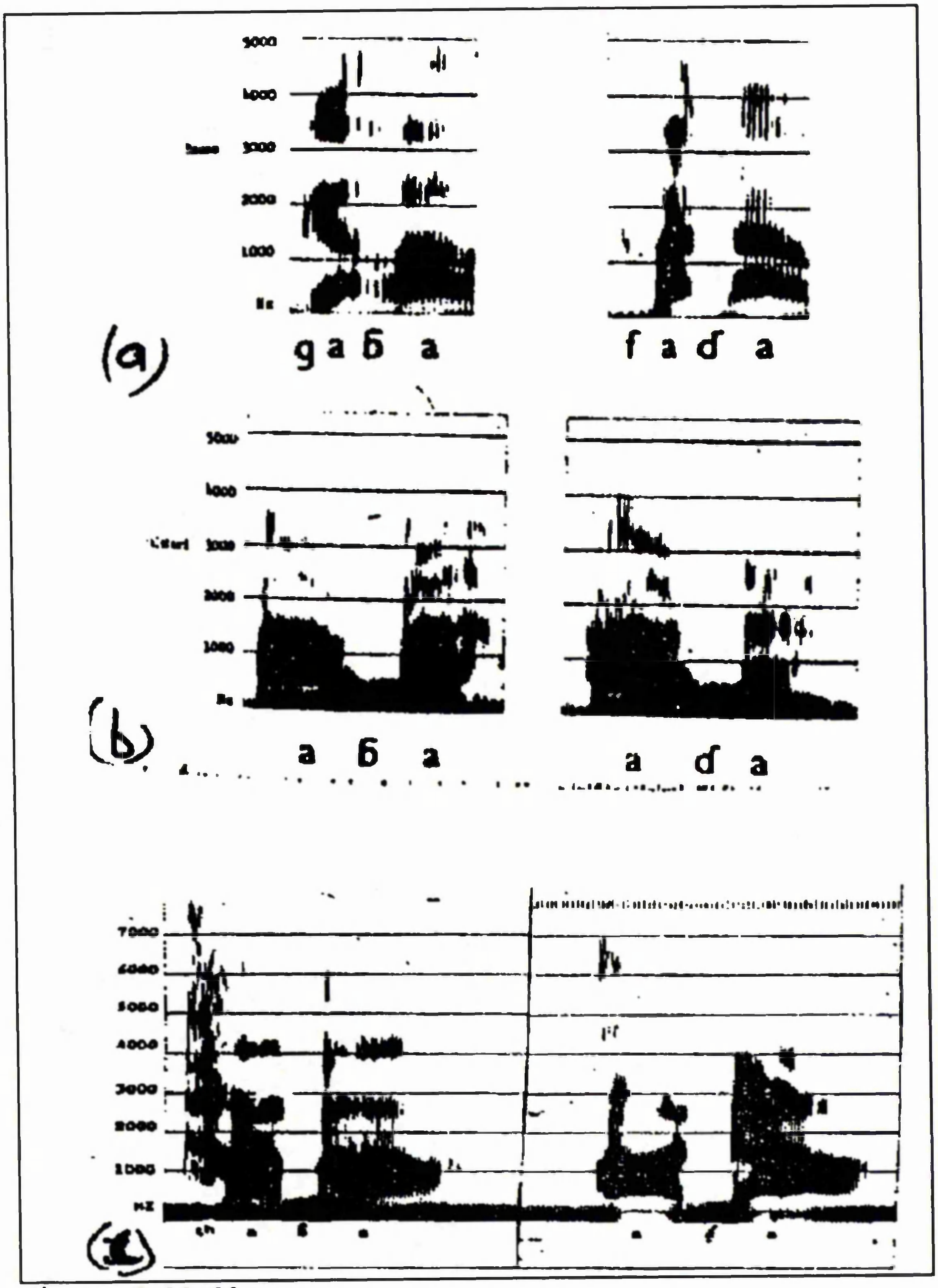



Figure 5.13.21:
(a and b) Spectrograms illustrating Hausa and Kalabari implosives.
(c) Sindhi implosives.
Source: Nihalani
(1986:120-121).

He compared the spectrograms of the implosive sounds in these languages with regard to periodicity of the glottal pulses.

Nihalani observed that Sindhi and Kalabari implosives are fully voiced throughout the period of closure. The spectrograms for the two languages show regularly spaced voicing striations throughout. As regards Hausa implosives, the spectrograms show a characteristic pattern which is marked by irregularly spaced voicing striations, indicating that there is laryngealized voicing throughout the closure. The author suggested that this characteristic pattern for Hausa implosives implies that they are produced with a very constricted glottis with greater muscular tension.

Pinkerton (1986) analyzed speech pressure waveforms of glottalic (implosive and ejective) stops and plain stop series in five languages of the Quichean (Mayan) family, a language spoken in Guatemala. The five languages studied were (1) K'ekchi, (2) Pocomchi, (3) Cakchiquel, (4) Quiche and (5) Tzutujil.

Pinkerton's aim was to obtain some reliable data about the phonetic voicing characteristics of the glottalized stops, particularly uvulars, in the Quichean languages. This is because she was concerned with explaining the general observation made by Greenberg (1970) that "front articulations favour implosives (bilabial place favoured) and back articulations ejectives (velar place favoured)." According to Pinkerton this could be explained with reference to the fact that implosives are voiced, rather than in terms of the nature of the airstream mechanism. The Quichean languages were a test case because they have uvular implosives.

Twenty seven male subjects between 17-32 years of age were recorded. Of these 15 were native speakers of K'ekchi, and the remaining 12 consisted of three each from the other languages. During the recordings, subjects read a prepared list of real words, embedded in a sentence. The list contained eight minimal pairs illustrating the glottalized/non-glottalized contrast in word-initial position and an additional eight minimal pairs showing the same contrast in intervocalic word-medial position. Each token appeared ten times in the corpus. Audio recordings were made using a tape recorder. Graphic recordings of the data recorded on tape were obtained using a Siemens Oscillomink ink writer oscillograph. The oscillograms were used to measure VOT following the stop series.

Sample tokens of the productions of one speaker of each of the dialects were used for analysis. The averages reported are based on the selected tokens of each given stop type. Her results are summarized as follows:

1 In Quichean languages, the stop inventories present a clear counterexample to Greenberg's prediction, as all these languages

> "realized their uvular glottalized stop as an implosive and yet do not have implosive at all points of articulation which are further forward; instead they have ejectives at the alveolar or velar places or both" (Pinkerton 1986:137).

2 It would therefore be true to say for both pulmonic and glottalic stop series that front articulations favour voicing and back articulations favour voicelessness. She remarked,

> "Implicationally, a voiced stop at a given place of articulation (within a given series) would indicate the existence of voiced stops articulated further forward. Voicelessness at a given place of articulation would imply the existence of voiceless stops articulated further back" (Pinkerton 1986:137).

3 She further says that,

> "Greenberg's predictions may have statistical validity since most implosives tend to be voiced and all ejectives must be voiceless; however, it is apparently not the implosive or ejective character per se which determines any pattern of the places of articulation at which these two types of glottalic segments are found. If the implosive or ejective character of a stop can be predicted on the basis of other co-occurring phonetic features, including place of articulation, these generalizations have yet to be discovered" (Pinkerton 1986:138).

Pinkerton did not provide any discussion on non-glottalized stops, saying that detailed analysis, especially quantitative analysis of the entire set was being prepared and would be presented in subsequent papers.

Ingram et al. (1987) have also given an acoustic analysis of glottalic (ejectives) and non-glottalic stops in Gitksan (a Tsimshianic language spoken in the Skeena River Valley of British Columbia). When Gitksan ejectives were compared with ejectives in other languages, substantial differences in manner of production were observed which the authors associated with a fortis-lenis distinction within the glottalic stops.

Two native speakers of Gitksan, one male (in his late thirties) and a female (the mother of the male subject) were recorded. They both read two words each. Both speakers were bilingual in Gitksan and English. For comparative purposes two examples of Chipewyan, an Athabaskan language with typical fortis ejectives, were also recorded from a single speaker. The Gitksan words were recorded on a Marantz cassette recorder (CP 430) and then digitized at a sampling rate of 20kHz. Waveform displays for plain and glottalized stops in word initial position were examined (cf. Fig. 5.13.22).

The following features of the signal were examined:

1 Amplitude envelope of oral release burst. Measurements were made of the maximum amplitude of the oral release burst where it could be observed independently of the vowel onset;
2 Voice onset time. The mean value of the VOT was calculated;
3 Amplitude envelope of the vowel onset. An index of the abruptness of the vowel onset was provided by the peak amplitude of the third glottal pulse as a proportion of the maximum amplitude achieved by the vowel (cf. Fig. 5.13.23);
4 The presence of aperiodicity and period by period fundamental frequency changes in the vowel onset, measured for the first eight glottal pulses (cf. Fig. 5.13.22).

The acoustic features are illustrated in Fig. 5.13.23 which shows the observed distinction of release burst amplitude measurements for the Gitksan glottalized stops as well as for the two reference tokens from Chipewyan. The amplitude measurements have been expressed as ratios of the maximum vowel amplitude for their respective tokens.

Gitksan glottalized stops were found to be characterized by:

1 a relatively weak but damped release burst, consistent with a lenis ejective airstream mechanism;
2 a shorter VOT than is typically observed for (fortis) ejective stops;
3 a gradual rather than abrupt vowel onset in the majority of tokens, though this feature varied with the speaker and was correlated with
4 an absence of visible aperiodicity in the waveform of the following vowel onset for the majority of tokens but nevertheless
5 substantial, but declining, pitch period perturbation

over the first glottal cycles of the vowel onset, with fundamental frequency contour rising (cf. Fig. 5.13.24); and

6 a considerable amount of inter-speaker variation in all of the above features with the male speaker consistently demonstrating a more lenis pattern of articulation.

7 The Chipewyan ejectives, on the other hand, are typical of the fortis type.

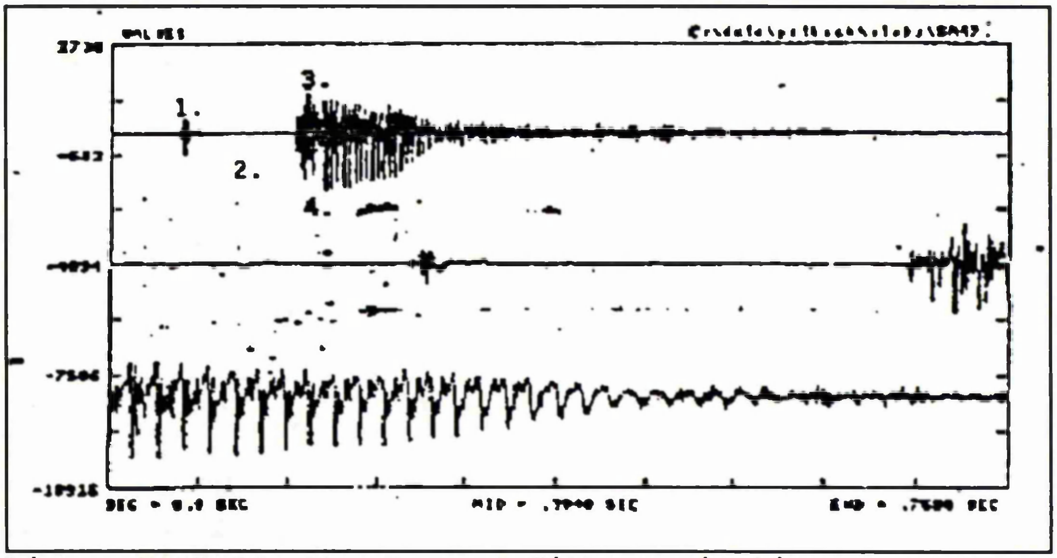



Figure 5.13.22: Waveform of Gitksan ejective.
Source: Ingram et al. (1987:135).

From the point of view of laryngeal configuration, Ingram et al. suggested that, physiologically, lower amplitude release burst and shorter VOT correspond to "reduced upward movement of the larynx" and gradual vowel onset rather than abrupt onset together with decreased pitch also indicates "a weaker medial compression, with lower overall muscular tension in the larynx" (Ingram et al. 1987:137).

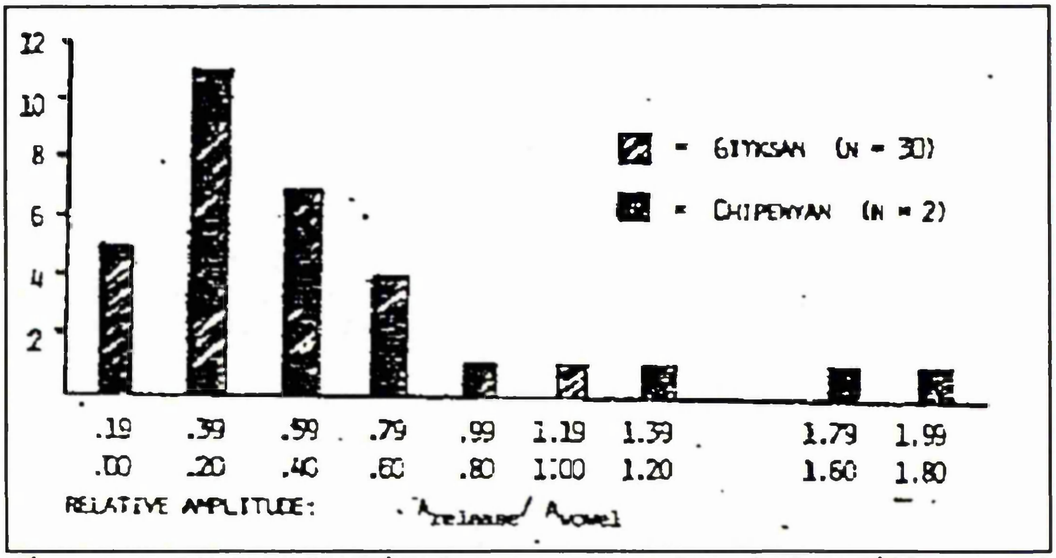



Figure 5.13.23: Amplitude of release burst for Gitksan and Chipewyan ejectives.
Source: Ingram et al. (1987:135).

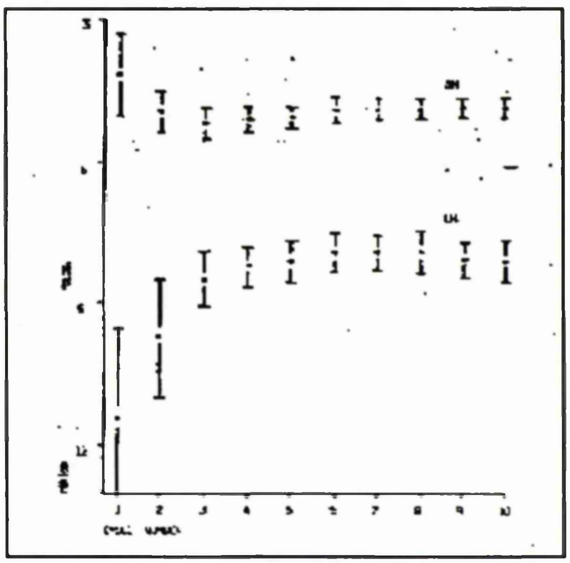


Figure 5.13.24: Period by period frequency changes in vowel onset.
Source: Ingram et al (1987:136).

They conclude with the following remark:

> "Analysis of the Gitksan data, taken in context of a growing body of data from other languages, suggests that a language typological distinction between fortis and lenis ejectives is warranted, where this term is understood in the traditional sense of the degree of vigour of the complex laryngeal and articulatory components which comprise the gesture" (Ingram et al. 1987:137).

## 5.14 Summary

To conclude, this chapter brings together descriptions of various instrumental techniques currently being used for characterizing different phonation types and describing contrast within and between languages. Instrumental data on phonation type contrasts and on glottalic consonants has been reproduced. A language index is provided in table 5.14.1.

Table 5.14.1: Table of Languages and Techniques used.

| **Language** | **Type of Contrast** | **Technique** | **Section and Page Number** |
|---|---|---|---|
| Chipewyan | ejective/ plain | Audio recordings | 5.13.3.2. p.417 |
| Burmese | modal/creaky voice | Inverse Filtering | 5.11.4. p.348 |
| Bumo | implosive/ plain stops | Audio Recordings | 5.13.3.2. p.417 |
| Dutch | modal voice phonating [a, i, æ, o & u] | Electro-glottography | 5.9.3. p.292 |
| English | *modal, whispery, extremely whispery, breathy, harsh, creaky, ventricular and falsetto | Laryngoscopy | 5.2.3. p.210 |
| | | Electro-laryngography | 5.9.4. p.305 |
| | *modal voice | Stroboscopy | 5.3.3. p.214 |

| | | | |
|---|---|---|---|
| | *modal voice | Ultra-high Speed Photography | 5.4.3. p.217 |
| | *modal voice | X-ray | 5.6.4. p.251 |
| | *modal voice | Photo-electric Glottography | 5.7.3. p.261 |
| | voiced/ voiceless plosives | Photo-electric Glottography | 5.7.3. p.261 |
| | *modal voice | Ultra Sound Glottography | 5.8.3. p.278 |
| | *modal voice/ pathological voice | Electro-laryngography | 5.9.3. p.292 |
| | voiced/voiceless [a] preceding stop consonants, /p/, /t/, /k/, /b/, /d/, /g/ and /ʔ/ | Aerometry | 5.12.3. p.363 |
| | voiced/ voiceless stops and fricatives | Electro-myography | 5.10.3. p.325 |
| | *modal voice | Inverse filtering | 5.11.3. p.345 |
| | modal, breathy and creaky voice | | 5.11.4. p.348 |
| Gitksan | ejective/plain stops | Audio recordings | 5.13.3.2. p.417 |
| Gujarati | breathy/ non-breathy vowels | Inverse filtering | 5.11.4. p.348 |
| | breathy/ non-breathy vowels | Aerometry | 5.12.3. p.363 |
| | breathy/ non-breathy vowels | Pitch & Intensity meter | 5.13.3.1. p.387 |

| | | | |
|---|---|---|---|
| | breathy/ non-breathy vowels | Spectrography | 5.13.3.1. p.387 |
| Hausa | glottalic/ plain stops | Audio Recordings | 5.13.3.2. p.417 |
| Hindi | voiced (un)aspirated/ voiceless (un)aspirated | Fibreoptics | 5.5.3. p.230 |
| | | Electro-myography | 5.10.3. p.325 |
| | voiced, breathy and aspirated plosive | Spectrography | 5.13.3.1. p.387 |
| Hmong | breathy/ non-breathy vowels | Inverse filtering | 5.11.4. p.348 |
| | modal, breathy, creaky voice | Spectrography | 5.13.3.1. p.387 |
| Igbo | breathy aspirated/ voiced plosives | Spectrography | 5.13.3.1. p.387 |
| !Xóõ | breathy/ non-breathy vowels [a] | Inverse filtering | 5.11.4. p.348 |
| | | Spectrography | 5.13.3.1. p.387 |
| Japanese | single/ geminate voiceless plosives | Fibreoptics | 5.5.3. p.230 |
| | voiced/ voiceless plosives | | 5.5.3. p.230 |
| | voiced/ voiceless plosives | Electro-myography | 5.10.3. p.325 |

| | | | |
|---|---|---|---|
| Javanese | voiceless breathy/ voiceless non-breathy | Electro-laryngography | 5.9.4. p.305 |
| | | Spectrography | 5.13.3.1. p.387 |
| Jalopa Mazetec | modal, creaky, breathy, voice vowels | Spectrography | 5.13.3.1. p.387 |
| Korean | aspirated, weak and strong plosives | Fibreoptics | 5.5.3. p.230 |
| | | Electro-laryngography | 5.9.5. p.314 |
| | | Electo-myography | 5.10.3. p.325 |
| | | Aerometry | 5.12.3. p.363 |
| | | Spectrography | 5.13.3.1. p.387 |
| | | Oscillography | 5.13.3.1. p.387 |
| Kalabari | implosive/ plain | Spectrography | 5.13.3.1. p.387 |
| | | Audio Recordings | 5.13.3.2. p.417 |
| Marathi | voiced/breathy nasals | Spectrography | 5.13.3.1. p.387 |
| Navaho | implosive/ plain plosives | Audio Recordings | 5.13.3.2. p.417 |
| Quichean (Mayan) | glottalic/ plain plosives | | 5.13.3.2. p.417 |
| Shona | voiced egressives/ implosives | Aerometry | 5.12.3. p.363 |
| Sindhi | voiced (un)aspirated/ voiceless (un)aspirated | | 5.12.3. p.363 |

| | | | |
|---|---|---|---|
| | implosives/ explosives | | 5.12.3. p.363 |
| | | Spectrography | 5.13.3.1. p.387 |
| Tigrinya | glottalic/ plain plosives | X-ray | 5.6.4. p.251 |

() = Optional. * = Phonation not intended to be contrastive in any language. Usually the vowel [a] or [i] is phonated at a sustained pitch or various pitches.

# PART THREE: THE INSTRUMENTAL INVESTIGATIONS, SUMMARY AND CONCLUSIONS

# Chapter Six

Description of Hausa Glottalic Consonants.

## 6.1 Introduction.

While there is no controversy about the place of articulation of most consonantal sounds in Hausa, the manner of articulation has long puzzled Hausa scholars. Most writers accept without debate the voiced/voiceless distinction in the language as in /k/ and /g/, but do not find it easy to group the glottalic sounds in a like manner. Although Hausa phoneticians are in general agreement that the phonemes /b'/, /d'/ and /'y/ have some glottalic features, a survey of the literature on Hausa shows several descriptions, as individual writers have held different views as to their nature.

## 6.2 Non-Instrumental Investigations.

Before the publication of Ladefoged's monograph (1964, 2nd ed. 1968), there had not been many instrumental investigations to establish the phonetic features that distinguish the Hausa glottalic stops from their plain counterparts. Most conclusions were derived not from instrumental investigations, but from articulatory and auditory analysis and impressionistic phonetic observations, supported by the then-known properties of glottalic consonants and inferences based on the classical model of the glottalic airstream mechanism (cf. Pike 1943).

Taylor (1923) gives an interesting description of /b'/ and /d'/. He says /b'/ and /d'/ are

> "made with a well-marked effort to expel the breath which is in the mouth without more coming through the vocal cords: technically there is closure of the glottis" (Taylor 1923:11).

He talks of the final "b" and "d" in "superb" and "band" as being almost the same sounds. I quote:

> "If the 'ban' of our 'band' is whispered and a pause made with the tongue in the N position and then the D is forcibly whispered a 'dotted D' will have been made, and if this d' is said with the ordinary voice and with the lips protruding, the d' for the Hausa word d'auki, take up, will have been approximately pronounced" (Taylor 1923:11).

The word "whispered" here suggests the authors perception of a decrease in the amplitude of vocal fold vibration noted in later instrumental studies (see below).

As for /k'/, he says it is produced by saying

> "ki in our 'king', and then producing it a little farther back with glottal closure (but without

turning it into a 'G' " (p.12).

He describes /'y/ as "a voiceless Y, produced with a glottal closure" (Taylor 1923:13). He did not discuss /ts/.

Robinson (1925) describes the glottalic sound /b'/ as one "in which the b has an explosive sound" (Robinson 1925:7). As regards the production of /d'/, he talks of

> "a hard d, in the pronunciation of which the point of the tongue touches the edge of the upper teeth, a sort of dt, which somewhat resembles the French or German t" (Robinson 1925:7).

He describes /k'/ as

> "a sub-palatal guttural k ... the person pronouncing this k puts his mouth into such a position that he appears to be shooting out water from the throat" (Robinson 1925:7).

He did not discuss /ts/ or /'y/.

James and Bargery (1925) say /b'/ and /d'/ are implosives accompanied by a simultaneous glottal closure and that they are produced with vibrating vocal folds while the larynx is drawn downwards. The description given here seems self contradictory. I quote: "b' and d'... are in reality implosive consonants ... made ... with simultaneous glottal closure" (James and Bargery 1925:723). They go on to say:

> "It is impossible to see what is happening, but it would appear that the glottis, with vocal folds in the position of voice, is drawn down through the air column. When the point of oral contact is released external air is drawn into the mouth" (James and Bargery 1925:723).

They call /k'/ and /ts/ ejectives and say that they are produced "with a simultaneous glottal closure, the glottal closure being released after the oral closure" (James and

Bargery 1925:724). They did not mention /'y/.

Westermann and Ward's (1933) practical manual for students of African languages considers Hausa together with Igbo and other West African languages not belonging to the Chadic family. Their description of /b'/ and /d'/ follows the traditional characterization of implosives, that is as glottalic ingressive sounds produced by lowering the vibrating glottis. They remarked:

> "Implosive consonants are sounds of a plosive nature, i.e. made by stop and release, in which the air is sucked inwards instead of being expelled" (Westermann and Ward 1933:92).

They call /k'/ and /ts/ glottalic egressive sounds (ejectives), and note that during their production the larynx is raised and there is a subsequent expulsion of the air compressed in the supraglottal cavity. Giving the phonetic description of the sounds, they say /k'/ is produced when "the glottis is closed at the same time as the mouth closure is made" (1933:96). They describe /ts/ as /s/ which is "made with simultaneous glottal closure" (1933:96). In their descriptions they left out /'y/.

Other articulatory descriptions have also stated that in most cases /b'/ and /d'/, like /ts/ and /k'/, are produced by a glottalic airstream mechanism; in other words, these pairs are implosive and ejective consonants respectively.

Bargery (1934) says,

> "The implosive b is formed by closing the lips without protrusion and then separating them in the vertical plane with a mild sucking in of the breath" (Bargery 1934:xxii),

and for /d'/ he says it is

> "formed by pressing the tongue against the teeth-ridge and releasing it with a light sucking in of the breath" (Bargery 1934:xxii).

He describes /k'/ as

> " ... an ordinary k produced simultaneously with glottal closure. The glottal closure is released after the velar closure" (Bargery 1934:xxii).

He calls /ts/ an ejective and gives several occurrences of it and its allophonic variations in the other dialects of Hausa. Citing examples from other dialects he says that it is not uncommon to hear an ejective /t'/ in Sokoto and Katsina where an ejective /ts/ is used in Kano. For example in Sokoto and Katsina **t'àbi?àa** > **tsàbi?àa** "behaviour/custom" in Kano. Similarly in Gobir, Sokoto and Katsina the ejective /ts/ is sometimes replaced by another ejective which Bargery represented as /c'/. For example, in Gobir, Sokoto and Katsina **c'inkèe** > **tsinkèe** "snap off" in Kano. Furthermore, he notes that in both Kano and Katsina another ejective which he represented as /s'/ is frequently heard instead of /ts/ (Bargery 1934:xxiii). See also chapter 2 section 2.4 for more examples on dialect variation. He describes /'y/ as a semi-vowel which he says is "sometimes preceded by a glottal closure" (Bargery 1934:xxiii).

Greenberg (1941) says that "b' d' and 'y are voiced implosives" (Greenberg 1941:316, fn. 3) and talks of /ts/ and /k'/ as sounds in which a glottal release follows oral release.

Hodge (1947) calls /b'/, /d'/ and /k'/ "glottalized consonants" and describes them as phonemes which correspond to the plain stops but which are "interrupted by a glottal stop, then released, followed by the release of the glottal stop" (Hodge 1947:9). He describes /b'/ as "bilabial glottalized voiced stop", /d'/ as "voiced glottalized dental stop", /k'/ as "voiceless glottalized velar stop" and /ts/ as "glottalized dental spirant" (Hodge 1947:8-10).

Abraham (1959a) calls /b'/ and /d'/ implosives. He remarks,

> "/b'/ and /d'/ are called implosive 'b' and 'd' because the breath is sucked inwards (instead of going outwards as is the case for the normal 'b' and 'd' of Hausa and English); /b'/ and /d'/ are accompanied by the glottal stop" (Abraham:1959a:2).

He talks of /k'/ and /ts/ as sounds "modified by being forcibly ejected and accompanied by a glottal stop" (Abraham 1959a:2). In another book (Abraham 1959b) he says,

> "Implosives /b'/ and /d'/ are fully voiced from the moment of forming the stop and are accompanied by closure of the glottis,i.e. are accompanied by glottal stop" (Abraham 1959b:141)

a statement which would seem to be self-contradictory. He describes /k'/ as a sound which is produced

> "by placing the back of the tongue against the soft palate in the k-position and having slightly compressed the air by action of the throat-muscles, release of the back of the tongue allows the compressed air to rush out accompanied by the sound of a distinct glottal stop and produces the ejective Q" (Abraham 1959:140).

He talks of /ts/ as a sound produced

> "by placing the tip of the tongue on the teeth-ridge for saying ts, we obstruct passage of the air through the mouth, release of the compressed air here producing the ejective ts ... the glottis opens just after the release of the ts-stop" (Abraham 1959:140).

He did not mention /'y/.

Hodge and Umaru (1963) say that /b'/ and /d'/ begin with a stop and are released with a glottal stop, but do not make any claim that they are implosives. As regards /k'/ and /ts/, they say the segments are articulated with velar closure (for /k'/) and a "normal" /s/ (for /ts/) and they "are released with a glottal stop" (Hodge and Umaru 1963:26). They did not mention /'y/.

Hoffmann and Schachter (1969) do not differentiate /b'/ and /d'/ on the one hand from /k'/ and /ts/ on the other, calling them all "glottalized plosives".

Kraft and Greene's (1973) description is both articulatory and auditory; they speak of /b'/ and /d'/, /k'/ and /ts/ as "glottalized consonants". That is, each is produced with a simultaneous glottal catch and released with a rather explosive quality. The /b'/ and /d'/, in addition, are often produced implosively, i.e. with the air stream pulled into the mouth rather than expelled from the mouth as with /k'/ and /ts/. They say "b' is like b, but with a simultaneous glottal catch, and an explosive quality to the release", and "d' is like d (though the tongue position is a bit farther back), but with a simultaneous glottal catch and an explosive quality to the release" (Kraft and Greene 1973:8). As regards /k'/ they say it is "like k, but with a simultaneous glottal catch and an explosive, click-like quality to the release", and "ts is like s, but with a simultaneous glottal catch and an explosive quality to the release" (Kraft and Greene 1973:8). They describe /'y/ as a "sound which consists of y preceded by a glottal catch" (Kraft and Greene 1973:8).

Kraft and Kraft (1973) write that

> "the glottalized consonants /b'/, /d'/,and /k'/ are produced by closure at the bilabial, alveolar and velar points of articulation respectively while the airstream is also cut off by closure of the vocal cords. Both closures are then released simultaneously ... In the case of the /b'/ and

> /d'/ an additional difference is the fact that frequently the airstream is reversed - being pulled into the mouth rather than emitted. These sounds are, therefore, often termed implosives" (Kraft and Kraft 1973:25).

They describe /ts/ as a

> "glottalized alveolar fricative. It is usually produced as an /s/ with simultaneous glottal closure. Alternatively it is a combination of /t/ plus /s/ with simultaneous glottal closure" (Kraft and Kraft 1973:25).

They describe /'y/ as a "palatal semi-vowel with simultaneous glottal closure" (Kraft and Kraft 1973:26).

The above review of the early literature shows that descriptions of the Hausa glottalic consonants are not entirely consistent with one another and are in some cases rather confusing.

## 6.3 Early Instrumental Investigations.

More recent instrumental studies of glottalic obstruents have revealed a greater range of cross-language and cross-speaker variation than was earlier envisaged. For Hausa, we may cite Carnochan (1952), Ladefoged (1968), Schuh (personal communication), Meyers (1976) and Lindau (1984). The instrumental data obtained include airflow traces, speech pressure waveforms, and spectrograms.

Carnochan (1952) made an instrumental study of Hausa glottalic stops. He said that during the production of /b'/ and /d'/ there is a

> "strained and constricted quality, followed by glottal closure and release" (Carnochan 1952:86).

His description of the glottalic consonants was based on impressionistic observation helped by the application of kymography and palatography. The parameters examined with the kymograph together with a larynx microphone were:

1 voicing characteristics, and
2 consonant duration.

Comparing the kymograph tracings of /b'/ and /b/ word medially, he noticed that /b'/ had very low amplitude displacement in the speech pressure waveform traces during and immediately after the release of the consonant. In the larynx tracings, he observed several irregular disturbances which he attributed to irregular opening of the vocal folds, suggesting that very little air was coming through the glottis. The speech waveforms of /b/ showed a continuous voicing, and on the larynx trace, there was no evidence of raising or lowering of the larynx. The results also showed that the glottalized consonants were shorter in length than their plain counterparts. "There is greater duration with v- prosody than with glottal prosody"

(Carnochan 1952:86).

With initial /b'/, he noticed that there is no regular waveform on the mouth trace as there is with "normal" voicing; rather there are certain irregular disturbances of the line which he explained as a result of less air escaping from the lungs. The larynx trace showed no regular waveform during the point corresponding to the closure for /b'/ (cf. Fig. 6.1).

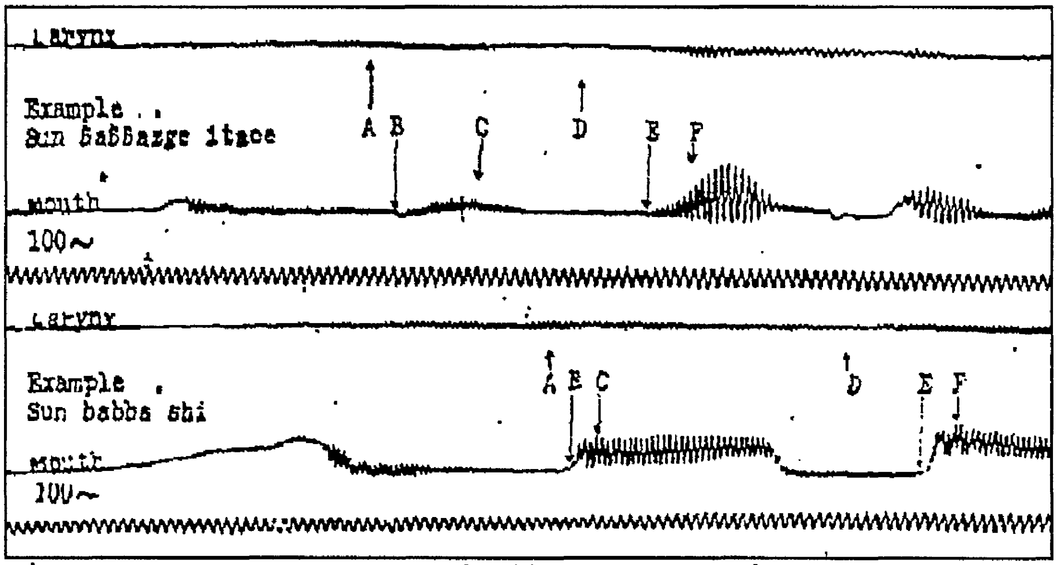



Figure 6.1: Kymograms of the Hausa phrases (a) **sun b'ab'b'azge itace** 'they peeled the bark of a tree many times' and (b) **sun babba shi** 'they gave him many times'. Source: Carnochan (1952:101).

As regards the quality of the segments immediately surrounding the glottalized consonants, Carnochan notes that they are produced with

> "a strained and constricted quality, a kind of creak" (Carnochan 1952:92).

He remarked:

> "There is a feature of glottalization in process through all this part of the sentence (contiguous to b'). It would be absurd to regard it merely as a feature of the consonant articulation" (Carnochan 1952:104-105).

Carnochan prefers to abstract glottalization as a suprasegmental feature, and discuss it within the framework of Prosodic Analysis. See Carnochan (1952) for his complete treatment of the concept of "glottal prosody".

He described /k'/ as a segment with a velar closure accompanied by glottalization:

> "both closures are made simultaneously, and the closed glottis is raised and compresses the body of air enclosed. It is the velar closure which is released first, with an explosion of this compressed air" (Carnochan 1952:105).

The kymograph tracings showed a time of 6-8 msecs between the release of the velar closure and the glottal release.

According to Carnochan, the palatograms show that the ejective /ts/ is produced without

> "complete closure between the tip and blade of the tongue and the alveolar zone" (Carnochan 1952:106),

and the palatograms for /'y/ show

> "a high front tongue position with the sides of the tongue touching the hard palate as far forward as the post-alveolar zone. During this articulation process there is no closure in the supraglottal area" (Carnochan 1952:106).

Carnochan did not give us any examples of his palatograms to illustrate the event he described.

Schuh (pers. comm.) obtained intra-oral air pressure recording and speech pressure waveforms along with spectrograms. The subject was a 26 year old male. The subject was not a native speaker of Hausa, but according to the author the subject had lived in Zinder (in the Republic of Niger) since childhood days and has a command of the language like that of any native speaker. Schuh concluded that (at least for his informant) for the greatest part of the length of /b'/ and /d'/, the glottis was completely closed. The speech pressure waveforms indicated that the sounds were completely voiceless, as did the spectrograms, which also showed that the formants and voice bar stopped simultaneously (Schuh did not give any diagram for /b'/) (cf. Figs. 6.2-6.6). The intra-oral air pressure showed a negative oral pressure (cf. Fig. 6.3). Schuh likened the glottalized palatal /'y/ to /b'/ and /d'/ because according to him all three segments are produced with a glottal stop accompanied by a consonant articulation (cf. Fig. 6.6 for /'y/). He talks of /ts/ and /k'/ as ejectives and says they are produced with a raised larynx (cf. Fig. 6.5 for /ts/). He did not give any illustration for /k'/.

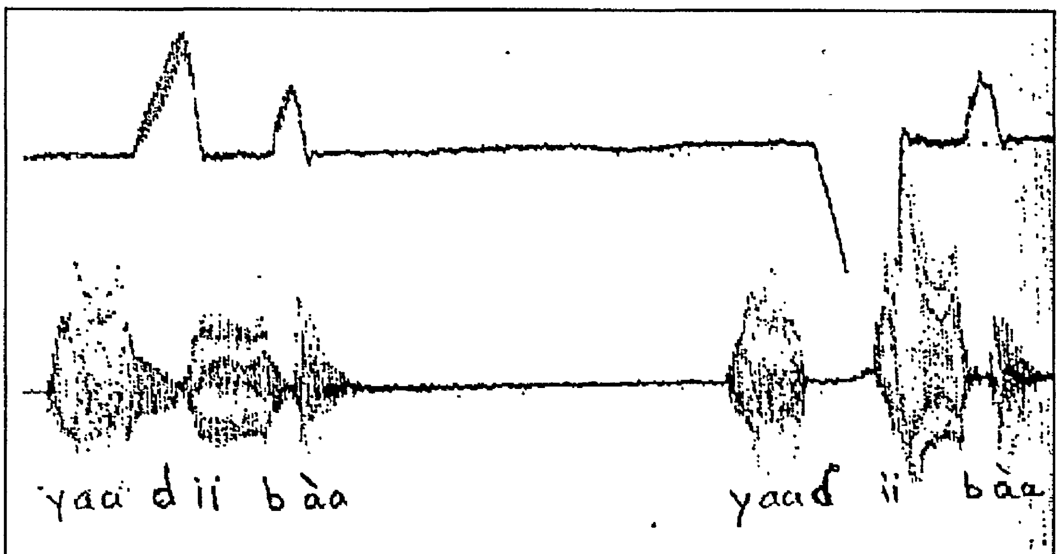



Figure 6.2: Airflow traces and speech waveforms for /b/ in the phrases **ya dii bàa** 'he looked at it' and **yaa d'ii bàa** 'he took it'. Upper trace: airflow; lower trace: speech waveform.

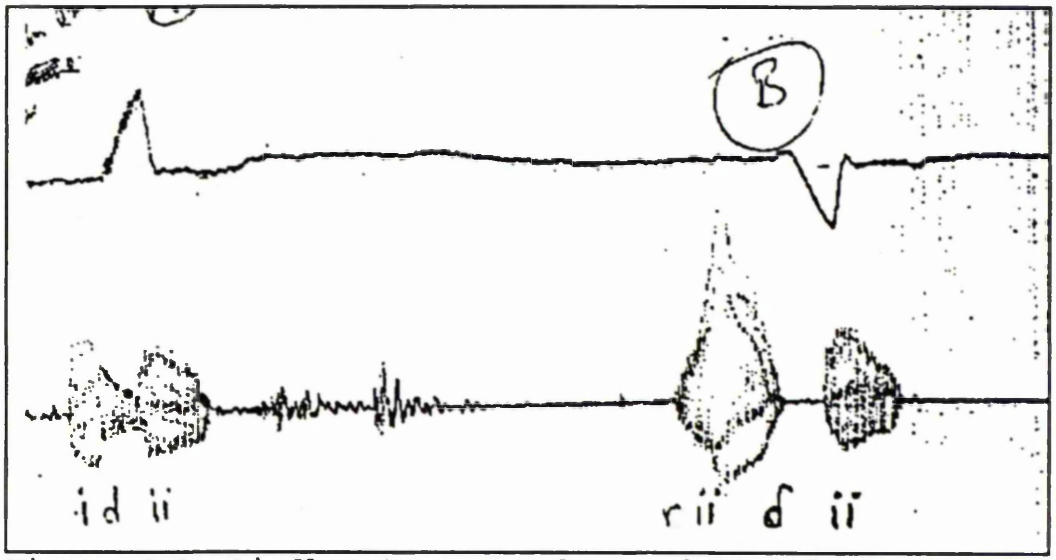


Figure 6.3: Airflow traces and speech waveforms for /d/ and /d'/ in the words **idii** 'person's name' and **riid'ii** 'beniseed, sesame seed'. Upper trace: airflow; lower trace: speech waveform.

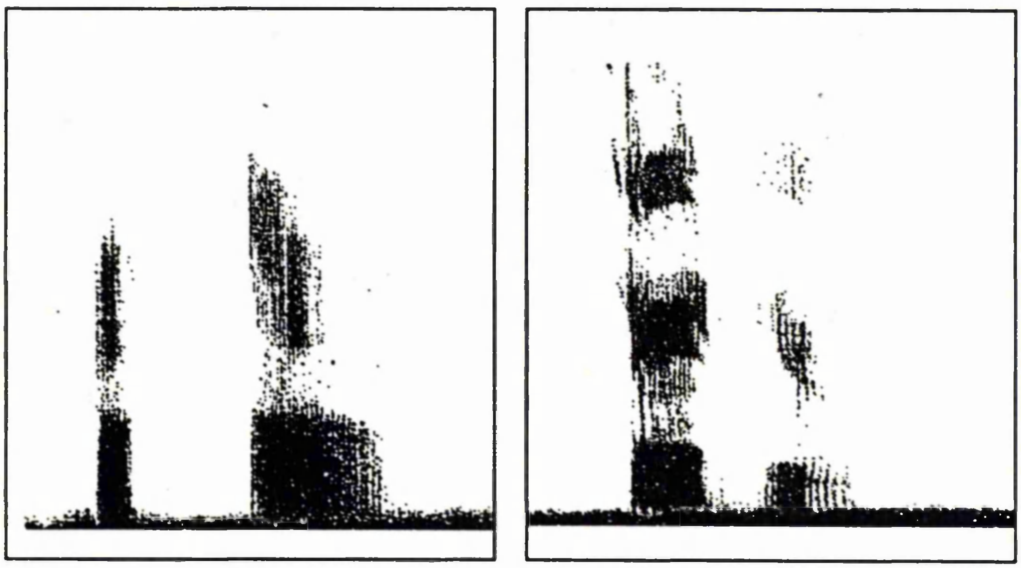
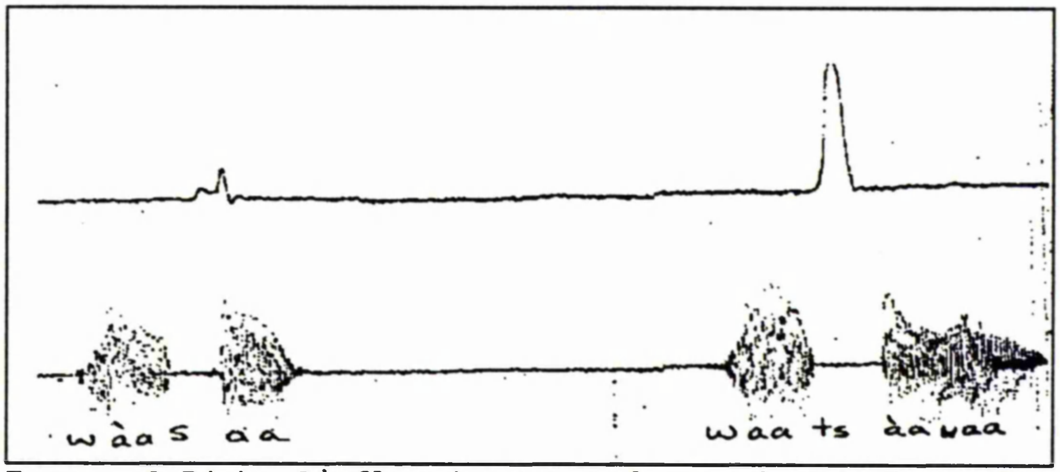


Figure 6.4 (a-b): Spectrograms of intervocalic (a) /d'/ and (b) /d/ in Hausa words **hud'u** 'four' and **tudùu** 'hill'.




Fugure 6.5(a): Airflow traces and speech waveforms for intervocalic /s/ and /ts/ in Hausa words **wàasaa** 'game, play' and **waatsàawaa** 'scatter'. Upper trace: airflow; lower trace: speech waveform.

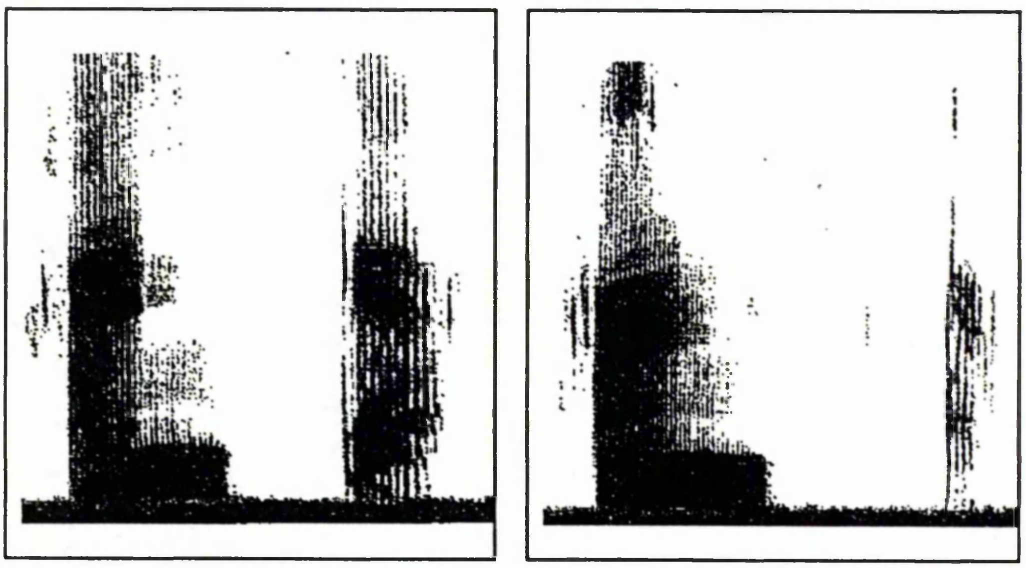


Figure 6.5 (b-c): spectrograms of (b) /t/ and (c) /ts/ segments in the words **hantàa** 'liver' and **hantsàa** 'sun rise' respectively.

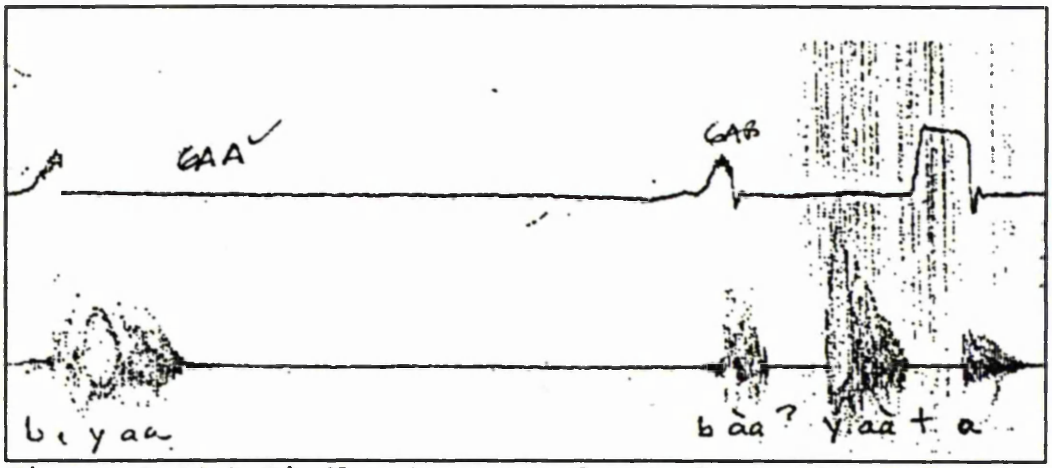



Figure 6.6(a) Airflow traces and speech waveforms for /y/ and /'y/ in **baayaa** 'back' and **baa 'yaa ta** 'give it to my daughter'. Upper trace: airflow; lower trace: speech waveform.

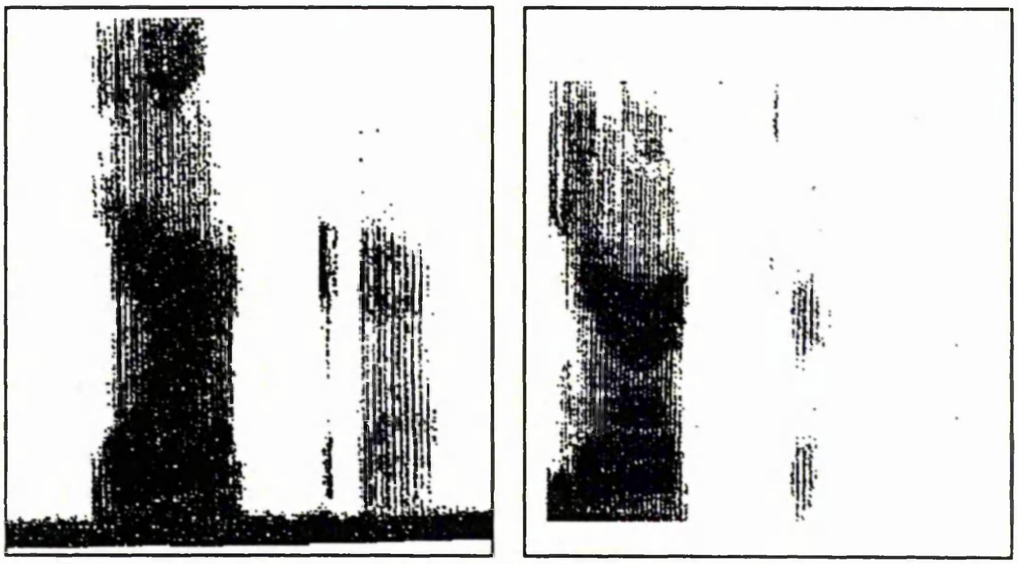


Figure 6.6 (b-c): spectrograms for the same segments in (b) **yaa kà** 'you come' and (c) **'yaa ta** 'my daughter'.
Source: Schuh (pers. comm).

Meyers' (1976) experimental investigation into the nature of Hausa tone and intonation (the only study to use electroglottography) devotes a section to the consonantal inventory of Hausa. Her claims about the phonetic nature of the Hausa consonantal inventory are based on experimental data obtained through the use of the electroglottograph combined with a computer program which extracts fundamental frequency measurements. A single subject was recorded reading several tokens containing the consonants under investigation (the number of utterances varied from segment to segment). She rejects earlier descriptions of the glottalic segments /b'/ and /d'/ as implosive sounds produced with vocal fold vibration, in other words, voiced (cf. Westermann and Ward 1933). She says that of the eleven recordings of /b'/ and /d'/ she made in initial and intervocalic position none showed any marked evidence of voicing, although the electroglottographic waveforms showed some irregular excitation during the initial portion of the consonants. She says that perceptually the segments had no audible voicing (cf. Figs. 6.7 and 6.8).

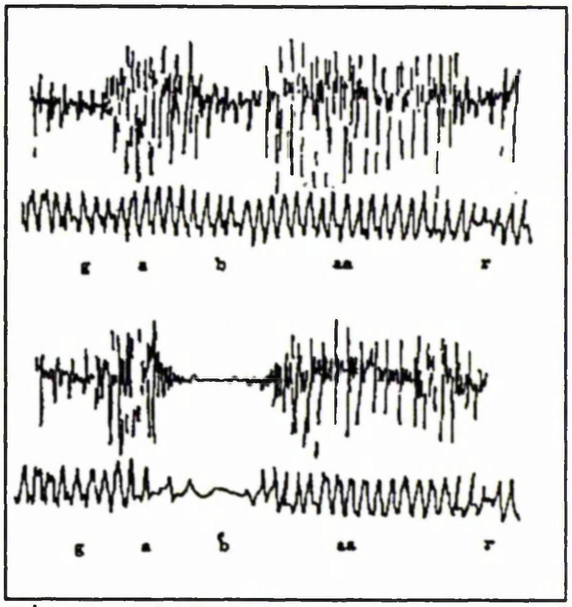


Figure 6.7: Waveforms and electroglottograph recordings of /b/ and /b'/ in the phases **ga baaruu** 'saw hyena' and **ga b'aaraaraa** 'saw loud talking'. Source: Meyers (1976:21).

Meyers also compared the characteristic patterns of the speech pressure waveforms and the electroglottograph outputs for /k/ and /k'/. She notes that neither /k/ nor /k'/ show evidence of voicing during the occlusion period, but the essential difference between the two sounds is that /k/ is aspirated immediately before the onset of voicing of the following vowel, while /k'/ shows a strong burst of noise after the release of the velar closure. (Fre Woldu (1985) has observed the same phenomenon in Tigrinya). This burst of noise is then followed by a period of irregular laryngeal activity lasting 40 msec before the onset of voicing of the following vowel (cf. Fig. 6.9 which shows recordings of /k/ and /k'/.

Meyers suggested that the irregular laryngeal activity following the velar release in /k'/ was due to the up and down movement of the larynx or irregular laryngealized voicing (Meyers 1976:24). She also compared the duration of /k/ and /k'/. The duration of the segments includes both the occlusion period and the aspiration phase immediately following it. She found that on average the glottalized segment was longer, lasting about 150 msec, while the plain one lasted 120 msec.

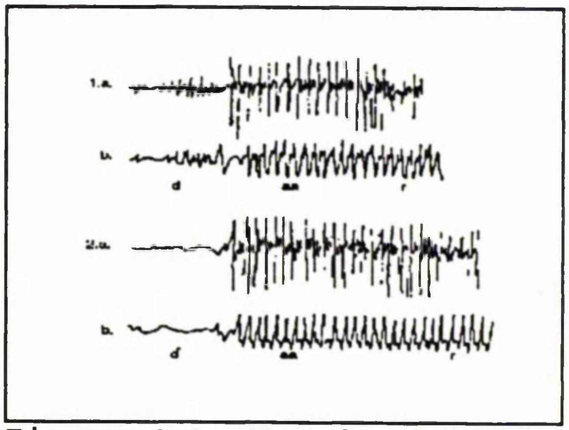


Figure 6.8: Waveforms and electroglottograph recordings of /d/ and /d'/ in the words **daaroorii** 'basins' and **d'aarii** 'cold wind'.
Source: Meyers (1976:23).

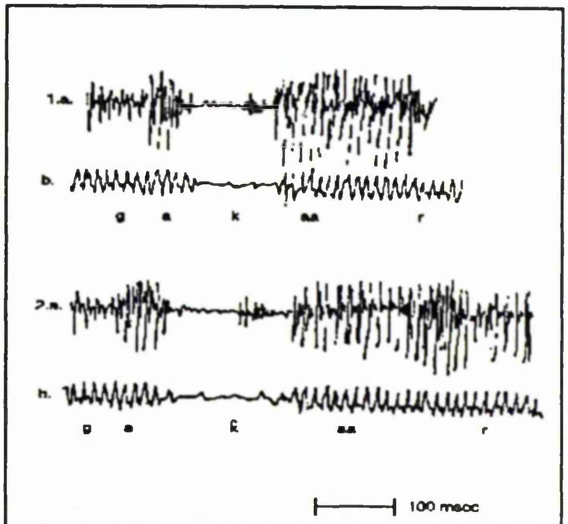



Figure 6.9: Examples and electrolaryngograph recording of /k/ and /k'/ in the phrases **ga kaaruwancii** 'saw harlotry' and **ga k'aarii** 'saw bad smell'.
Source: Meyers (1976:25).

She described /ts/ as a "laryngealized fricative" usually produced with initial friction and then followed by a period of voicelessness. She also noted that the segment was longer than its plain counterpart. It averaged 120 msec in length, while the non-glottalized consonant averaged 80 msec (cf. Fig. 6.10).

From her fourteen recordings of /'y/ Meyers observed that the vocal folds were apparently tightly closed for at least 35 msec (since there was no speech waveform for this length of time); then, when they did start vibrating, there were glottal pulses irregularly spaced for an average period of 60 msec (cf. Fig. 6.11). However, in some of the recordings a great deal of variation with regard to the period of voicelessness was observed (not only in the glottalized consonant /'y/ but also in /b'/ and /d'/).

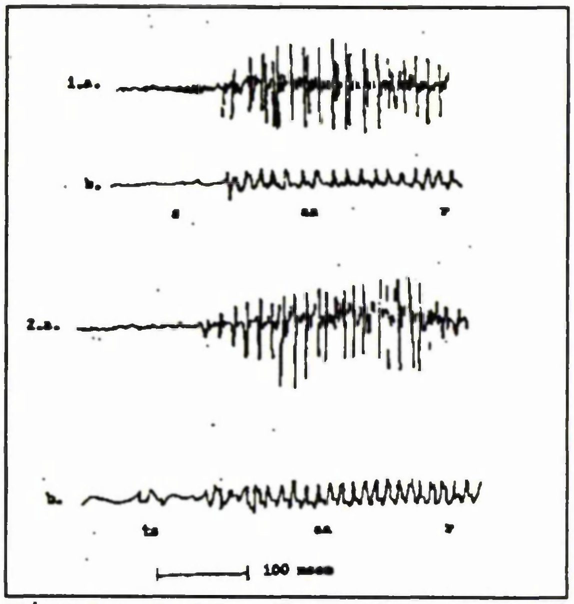


Figure 6.10: Examples and electrolaryngraph recordings of /s/ and /ts/ in the words **saaraa** 'chopping' and **tsaaraa** 'age-mate, equal'.
Source: Meyers (1976:26).

In his well-known <u>Phonetic Study of West African Languages</u> (1964, 2nd ed. 1968), Ladefoged made the first major contribution of broad scope in the area of instrumental phonetic studies of African languages.

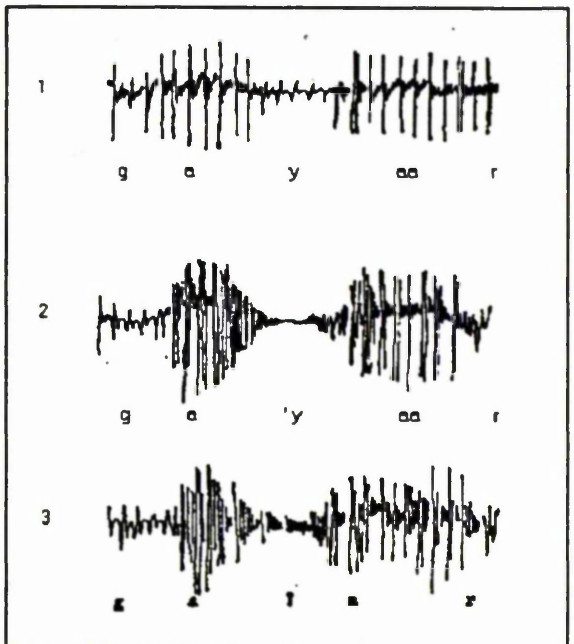



Figure 6.11: Illustrations of waveform recordings of /y/, /'<u>y</u>/ and /<u>ʔ</u>/ in phrases **ga yarbaawaa** 'saw Yorubas', **ga 'yar <u>ʔ</u>uuwaa** 'saw sister' and **ga <u>ʔ</u>areewaawaa** 'saw Northerners'.
Source: Meyers (1976:28).

With regard to the Hausa glottalic consonants, Ladefoged claims that the Hausa phonemes /b'/ and /d'/ may involve a downward movement of the glottis but that the "essential component is a particular mode of vibration of the vocal cords" (Ladefoged 1968:6).

He therefore calls them laryngealized because they are "incidentally implosive on some occasions" and are distinguished from the other Hausa plosives primarily by being laryngealized. Laryngealized voicing may or may not occur in true implosive consonants, and equally it can occur without the downward movement of the larynx which must (by definition) be present during the articulation of an implosive.

The amplitude of these sounds is reduced because there is less air passing through the glottis when the vocal folds are vibrating. Cross-linguistically, Ladefoged says that it is possible to

> "separate out two kinds of glottalised consonants: what we are here calling voiced implosives (as in Igbo and Kalabari), in which there is always a downward movement of the glottis - and there may or may not be laryngealised voicing; and what we are here calling laryngealised consonants (as in Hausa), in which there is always a particular mode of vibration of the vocal cords - and there may or may not be a lowering of the larynx" (Ladefoged 1968:16).

He speaks of the difficulty in distinguishing between laryngealization and glottal closure; whereas in Chadic languages (Hausa, Bura and Margi) we have laryngealization, in the other West African languages (Serer, Wolof and several dialects of Fula) we find glottal closure.

Concerning the ejective /k'/, Ladefoged notes that there is a greater voicing delay than after its plain counterpart:

> "The stops in this series were accompanied by an interval of 50-60 msec between the release of the closure and the start of the vowel. This is slightly longer than the period of aspiration

"following the corresponding stops, c, k, kw, which usually lasted about 35-45 msec" (Ladefoged 1968:5).

He goes on to say that the increase in the voiceless period may be associated with the timing required for the glottis to return to the position necessary for normal voicing (Ladefoged 1968:5).

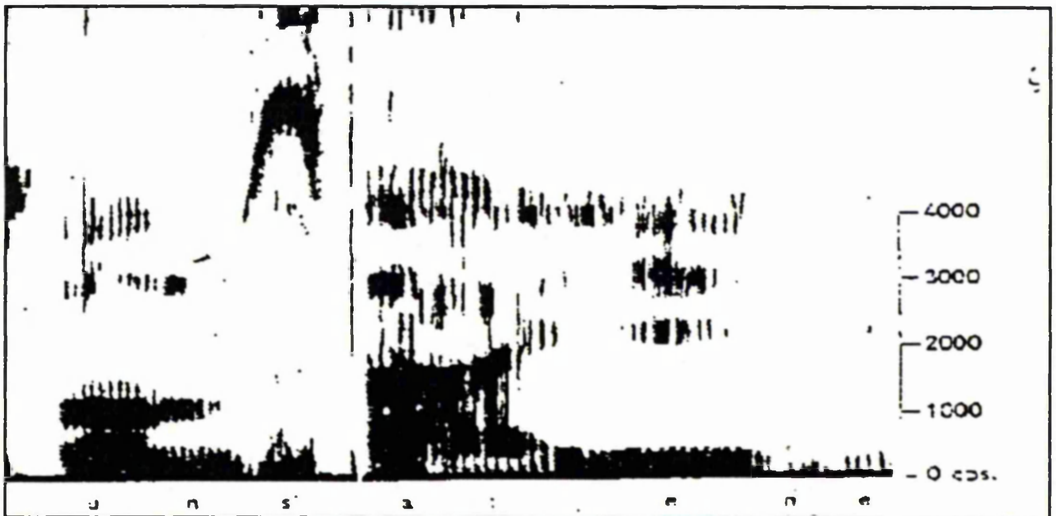



Figure 6.12: A wide-band spectrogram illustrating Hausa [s'] in Hausa phrase **tsuntsàayee nèe** "they are birds". Source: Ladefoged (1968:43).

As regards the ejective /ts/, Ladefoged describes it as ejective fricative [s'] (cf. section 6.9.2 for detailed discussion). He says the segment is produced with

> "an interval of about 40 msec between the end of the recorded fricative sound and the release of the glottalic stop and a further short interval before the vocal folds start vibrating" (Ladefoged 1968:5-6) (cf. Fig. 6.12).

He further suggests that the

> "up-and-down movement of the glottis can be correlated with a movement of the point of articulation which causes a variation in the pole frequency associated with the fricative noise (Ladefoged 1968:5).

Also of interest is Hausa /'y/. Ladefoged describes a waveform of this segment in an intervocalic position as beginning with a short period of voicelessness. The vocal folds are "apparently tightly closed" and this is followed by four irregular pulses of vibration, then a gap (which he feels he cannot positively claim is a glottal stop), then irregular vibration.

Ladefoged groups /b'/, /d'/ and /'y/ together. He points out that this segment is acoustically extremely similar to /b'/ and /d'/ in that all three have a particular mode of vibration of the vocal folds. He remarked,

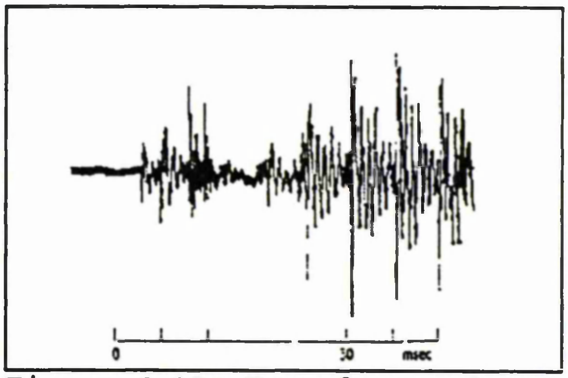



Figure 6.13: Example of a waveform showing irregular vibrations of the vocal folds during an intervocalic laryngealized palatal /'y/ in Hausa word **'yaa'yaa** 'children' .
Source: Ladefoged (1968:43).

> "It is easy to see that in the case of the consonants 'w (in Bura and Margi) and 'j (in Hausa), the difference is the mode of vibration of the vocal cords; these sounds are never literally implosive. My observations indicate that the same mode of vibration of the vocal cords occurs in the other consonants b' and d'; these sounds may be incidentally implosive on some occasions; but they are always distinguished from their voiced counterparts by being laryngealized" (Ladefoged 1968:16).

Although Ladefoged's book is rich in instrumental data on implosives, it is not rich in Hausa data. He does not provide us with any spectrograms, speech pressure waveforms, air flow traces, air pressure traces or palatograms to illustrate the Hausa /b'/, /d'/ and /k'/, though there is a spectrogram of /ts/, and a speech pressure waveform of /'y/ (cf. Figs. 6.12 and 6.13). It is therefore not always clear what evidence his descriptions are based on. Furthermore Ladefoged's investigations consider Hausa with other West African languages not belonging to the same family (Chadic). It is therefore not surprising we find different realizations in the production of the consonants.

Lindau (1984) is close to Ladefoged in her approach. She analyzed speech pressure waveforms and spectra of glottalic consonants in Hausa and four other West African languages (namely Degema, Kalabari, Okrika and Bumo), plus one Athabascan language, Navaho. In Hausa, 14 native speakers were recorded. In all cases the utterances contained the glottalic consonants in intervocalic position between the vowel /a/ in real Hausa words spoken within a frame. Each utterance was repeated three times by each speaker and the middle token was selected for analysis. For the so-called "implosives" analysis was based both on waveforms and on spectra, while the analysis of the glottalized palatal and ejectives was based on waveforms only.

Comparing Hausa ejectives with ejectives in other languages, Lindau observes that Hausa has significantly shorter closure durations than the other languages. For example the **ejectives** in Navaho have more than twice the average duration of those in Hausa. Furthermore the two languages differ in the relative durations of the different parts of the ejectives. She remarks,

> "The closure duration in Hausa is about twice that of the VOT part, while the closure duration in Navaho is only 1.5 times as long as the VOT" (Lindau 1984:154).

Examining the speech pressure waveforms of the two languages, Lindau notes considerable differences in the characteristic patterns of the speech pressure waveforms of the following vowel. She remarks,

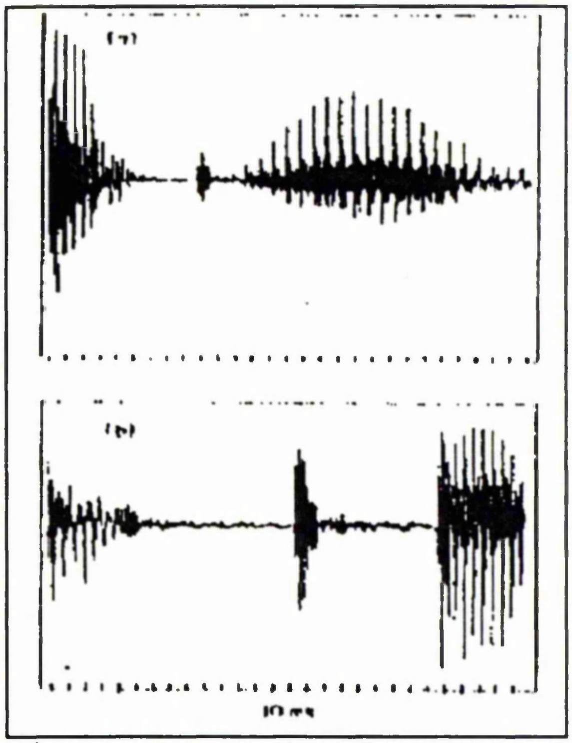


Figure 6.14: Waveforms of intervocalic velar ejectives in Hausa and Navaho.
Source: Lindau (1984:154).

> "In Navaho the glottal release coincides with the vowel onset, so the vowel starts with a sharp large amplitude. In Hausa, the glottal release occurs together with the oral release, and the vowel begins gradually, with aperiodic vibration" (Lindau 1984:154).

See Fig. 6.14 which shows the waveforms of intervocalic velar ejectives in the two languages.

According to Lindau,

> "This aperiodicity of the vowel onset after the ejective could be an important cue for differentiating voiceless plosives and ejectives in Hausa, since the Hausa velar plosive is followed by periodic onset of the vowel" (Lindau 1984:154).

Another interesting fact noted by Lindau was that some of her (Hausa) subjects produced /k'/ as a weak ejective or even non-ejective:

> "The results show that ejectives also display a great deal of variation between speakers in Hausa. Eight of the twelve Hausa speakers realized the ejective /k'/ phoneme as ejective. The other four speakers realized it as an unaspirated [k] or as a voiced [g]" (Lindau 1984:153).

Lindau did not discuss the ejective /ts/ in her paper.

As regards the implosives, Lindau assessed the following:

1 Voicing amplitude. This was measured between two points marked by arrows in the middle of the stop closure and at the end of the closure (cf. Fig. 6.15). The choice of middle rather than the beginning of the closure, according to the author, was due to the considerable variation in the onset of implosion. The peak to peak amplitude of voicing was averaged for all the glottalic consonants in the chosen languages. A ratio of amplitude at the two points was calculated by dividing the amplitude at the end by the amplitude at the middle. This end-to-middle amplitude ratio was calculated and averaged for all bilabial and alveolar implosives in all the languages she investigated, except that five out of the fourteen Hausa speakers who produced the implosives with (nearly) voiceless closures were excluded from this measurement.

2 Closure duration. This was measured from the offset of the preceding vowel to the onset of the following vowel. These points were reasonably easy to mark due to sharp changes in amplitude. The closure durations were averaged for all the speakers of each language, except that the five Hausa speakers who produced implosives with (nearly) voiceless closures were again excluded from the measurements.

3 Characteristic patterns of the waveforms were examined in a qualitative way using the periodicity of the waveforms and spectral shapes at selected points to arrive at a conclusion about phonation types.

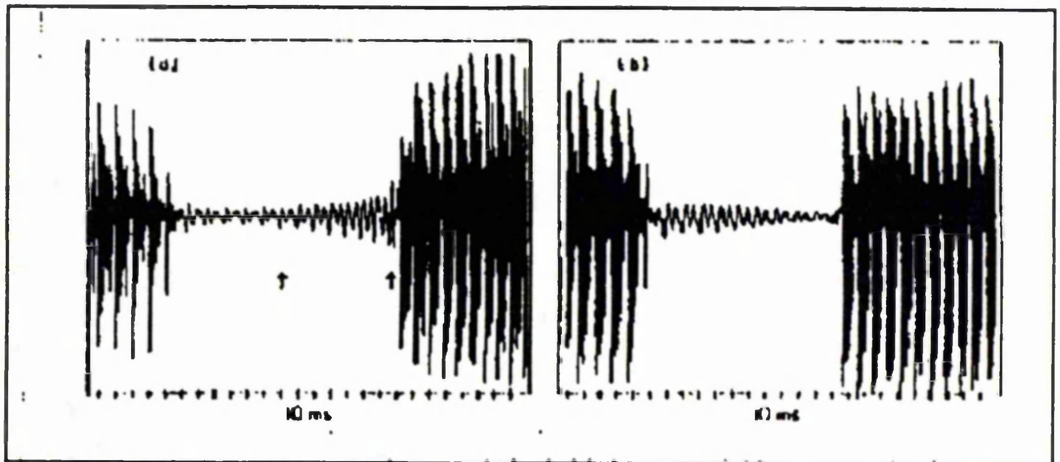


Figure 6.15: Waveforms of (a) an implosive /b'/ showing the points measured and (b) an intervocalic plosive /b/ in Degema.
Source: Lindau (1984:149).

Lindau notes that Hausa implosives show the highest end-to-middle amplitude ratio which according to her indicates a higher degree of implosion than occurs in the other languages (cf. Fig. 6.16). She also notes that "Hausa has significantly shorter closure duration than the other languages" (cf. Fig. 6.17).

Examining the speech pressure waveforms of the implosives in the Niger-Congo languages and comparing them with Hausa, Lindau observed that the waveform pattern during the closure phase in the Niger-Congo languages displays a considerable amount of high frequency energy in the first part but the latter part of the closure shows a waveform which looks as if it is produced with modal phonation. The spectrum shows a velar formant structure. See Fig. 6.18 which shows a typical waveform and spectrum of the bilabial implosive /b'/ in Bumo which is typical of the voiced implosives in the four Niger-Congo languages. Lindau suggested that the high frequency energy in the waveform

> "is possibly due to the vocal folds vibrating with a relatively sharp closure while they are being held tightly together in the descending larynx and this results in cavity resonances. The first part of the closure in these languages is thus typically produced with a form of laryngealization, but the latter part of the closure looks on the waveform like it is produced with modal phonation" (Lindau 1984:151).

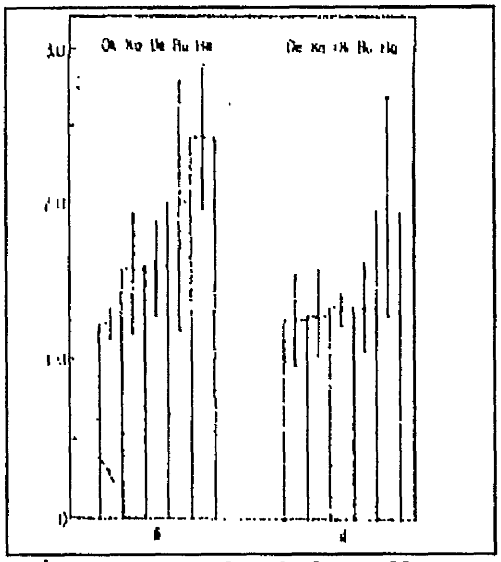


Figure 6.16: Mean end-to-middle amplitude ratios of labial and alveolar implosives in Okrika (Ok), Kalabari (Ka), Bumo (Bu), Degema (De) and Hausa (Ha). The bars indicate one standard deviation above and below the mean.
Source: Lindau (1984:150).

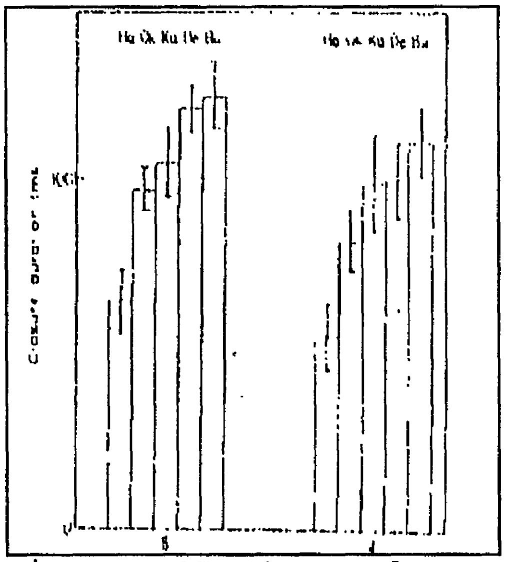


Figure 6.17: Mean closure durations of labial and alveolar implosives in Hausa (Ha), Okrika (Ok), Kalabari (Ka), Degema (De) and Bumo (Bu). The bars indicate one standard deviation above and below the mean.
Source: Lindau (1984:150).

For the implosives in Hausa, she notes that /b'/ displayed a closure phase which shows highly aperiodic vibrations and the spectrum shows no clear formant structure but with a peak around 3500Hz. According to Lindau the aperiodic vibrations are due to inefficiently closing vocal cords (cf. Fig. 6.19). She calls this "laryngealization". To quote more fully:

"The so called implosives in Hausa should not be labelled implosives, but rather be subsumed under a category of laryngealisation as proposed by Ladefoged 1968" (Lindau 1984:152).

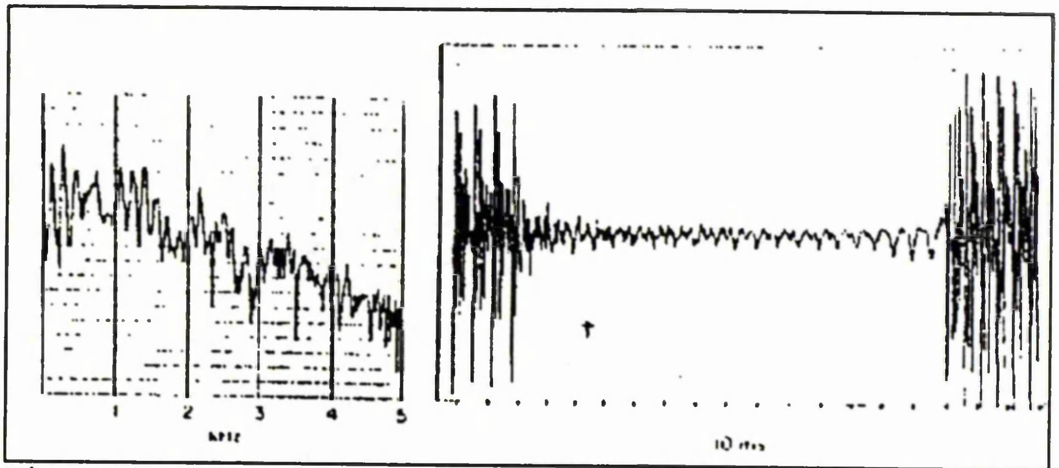



Figure 6.18: (a) Spectrum and (b) waveform of an intervocalic implosive in Bumo. The spectrum window was 50 msec, centred at the arrow.
Source: Lindau (1984:151).

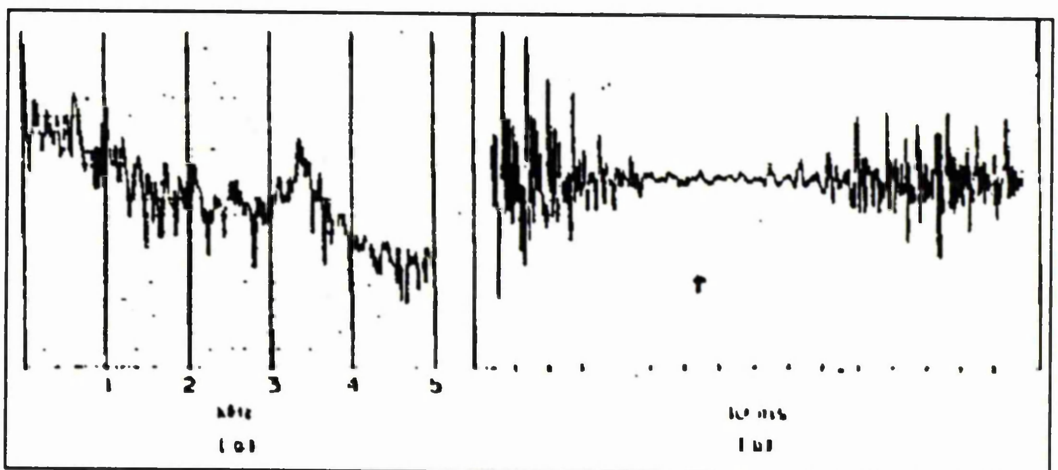



Figure 6.19: (a) Spectrum and (b) waveform of bilabial implosive in Hausa. The spectrum window was 50 msec centred at the arrow.
Source: Lindau (1984:152).

Lindau also noticed considerable variation between speakers: I quote:

"Five out of the 14 speakers produced a voiceless beginning of the closure; presumably from a glottal closure as the larynx descends. One speaker produced an implosive just like those in the Niger-Congo languages. The eight remaining speakers produced an implosive as seen in [Fig. 6.19]" (Lindau 1984:151).

As regards the **glottalized palatal** /'y/, Lindau describes it as one produced with an extreme kind of laryngealization different from /b'/ and /d'/ (contrast Ladefoged's comment on the similarity of /b'/, /d'/ and /'y/). The waveform exhibits

"a very low fundamental frequency, about 35Hz, and a high damping of the sound wave, indicating a large amount of high frequency components" (Lindau 1984:153).

In her view, this phenomenon resembles an extreme version of the laryngealization found in the beginning of the Niger-Congo implosives (cf. Fig. 6.20).

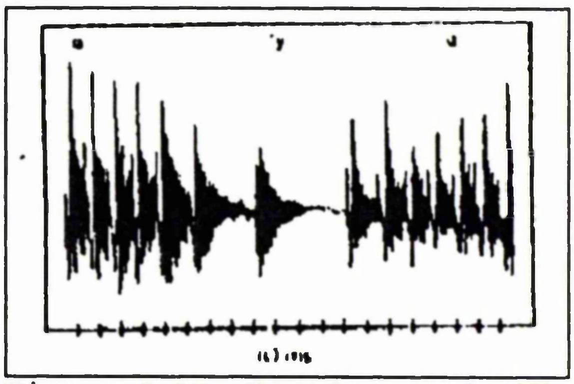


Figure 6.20: Waveform of the laryngealized palatal /'y/ in Hausa.
Source: Lindau (1984:152).

### 6.3.1 Summary: Review of Previous Studies.

The purpose of reviewing the above studies is to bring out the need for further instrumental investigation of Hausa glottalic consonants. As seen already the Hausa sounds /b'/ and /d'/ have been variously described as: implosive accompanied by glottal stop, Abraham (1959a and b); voiced implosive, Greenberg (1941); double articulated /b/ or /d/ with a simultaneous glottal stop, Taylor (1923), James and Bargery (1925), Hodge (1947), and Hodge and Umaru (1963); double articulated with an implosive airstream mechanism, Kraft and Kirk-Greene (1973) and Kraft and Kraft (1973); glottalized, Carnochan (1952), Hoffmann and Schachter (1969); or voiceless implosives, Schuh (personal communication) and Meyers (1976). Ladefoged (1968) asserts that they are characterized by a particular mode of vocal folds vibration (which he calls laryngealization) and that they are incidentally implosive on some occasions. This is also essentially the description given by Lindau (1984). She calls them laryngealized, produced frequently but not always with an ingressive airstream; she also points out that there is a good deal of variation between speakers.

The glottalized /ts/ also received several descriptions. James and Bargery (1925), Greenberg (1941), Hodge and Umaru (1963), Kraft and Kraft (1973) and Kraft and Greene (1973) describe it as a normal /s/ produced with a glottal release. Hodge (1947) calls it a glottalized consonant. As for Abraham (1959a & b), he says it is a sound which is modified by being forcibly ejected and accompanied by a glottal stop. Carnochan (1952) gives an articulatory description and says it is a sound produced without a complete closure between the tip and blade of the tongue and the alveolar region. Bargery (1934) and Ladefoged (1968) call it an ejective (cf. above for definition). Meyers (1976) calls it a "laryngealized fricative" and says it is produced with an initial friction. Robinson (1925) and Lindau (1984) did not treat it in their works.

As regards /k'/, Taylor (1923) and Bargery (1934) say it is an ordinary /k/ which is produced with a glottal closure. Robinson (1925) calls it a "sub-guttural /k/". Westermann and Ward (1933), Ladefoged (1968), Meyers (1976) and Lindau (1984) call it an ejective. Hodge (1947) describes it as a "voiceless glottalized velar". Abraham (1959a & b) describes it as a sound which has been modified by being forcibly ejected and accompanied by a glottal stop. Hodge and Umaru (1963), Greenberg (1941) and James and Bargery (1925) say it is a sound articulated with the velar as in /k/, accompanied by a glottal stop release, and Hoffmann and Schachter (1969), Kraft and Kraft (1973) and Kraft and Greene (1973) all call it a "glottalized consonant".

The glottalized /'y/ is described by Taylor (1923) as a voiceless /y/ produced with a glottal closure. Kraft and Kraft (1973) call it a "palatal semi-vowel with simultaneous glottal closure" (Kraft and Kraft 1973:26). Bargery (1934), Kraft and Kirk-Greene (1973) and Schuh (pers. comm.) say it is a semi-vowel which is (sometimes) produced with a glottal stop. Greenberg (1941) calls it a "voiced implosive". Ladefoged (1968) and Lindau (1984) describe it as a laryngealized consonant articulated with creaky voice. Meyers (1976) calls it a sound produced with a tight glottis. Carnochan (1952) defines it as a consonant articulated with high front tongue position, with the sides of the tongue touching the hard palate as far forward as the post-alveolar area. Robinson (1925), Westermann and Ward (1933) (for Hausa), Hodge (1947), Abraham (1959a & b), Hodge and Umaru (1963) and James and Bargery (1925) did not mention it.

## 6.4 The Problems.

In the sections above, we have seen that most impressionistic treatments of Hausa glottalized phonemes have spoken of a "glottalic airstream mechanism" in the production of /b'/, /d'/, /ts/ and /k'/, "implosive" and "ejective" in IPA terminology. As regards /'y/, most descriptions tend to say that it is preglottalized, i.e. a palatal semi-vowel preceded by a glottal stop or produced simultaneously with a glottal stop closure.

However, in the few instrumental studies, notably those of Carnochan, Ladefoged, Lindau and Meyers, it has been noted and generally agreed that Hausa /b'/ and /d'/ are not "classical" implosives and to simply call these consonant phonemes "implosive" might be an over-simplification, if not a falsification, of the phonetic facts. To quote Ladefoged (1968):

> "Published phonetic descriptions indicate that there is often a confusion between sounds such as /b'/ in Igbo and Kalabari, in which one of the essential components is a downward movement of the glottis, and /b'/ in the West Atlantic (Fula, Serer, Wolof) and Chadic (Hausa, Bura, Margi) groups of languages. In the latter case there may be a downward movement of the glottis, but the essential component is a particular mode of vibration of the vocal cords" (Ladefoged 1968:6).

Although this view has found general acceptance, the following gaps exist in and questions arise from previous instrumental studies.

1 More research is needed on the nature of /b'/ and /d'/ and their relationship to /'y/. Although Ladefoged and Lindau agree on their being laryngealized instead of implosive, Meyers thinks they are "voiceless unaspirated stops, perhaps having simultaneous glottal closure" (Meyers 1976:30). Ladefoged (1968) says /b'/,

/d'/ and /'y/ are similar with regard to the nature of laryngealization, whereas Lindau says /'y/ is different and that it is

"like an extreme version of the laryngealization found in the beginning of the Niger-Congo implosives, and not like the laryngealization found in Hausa implosives" (Lindau 1984:153).

2 Some of Lindau's subjects produced /k'/ as weak ejectives and even non-ejectives. It would be interesting to examine more speakers to see if the same is observed again.

3 Lindau and Ladefoged based their conclusions on speech pressure waveforms and spectrograms. Although acoustic recordings might give some useful information regarding larynx activity, particularly in the consonantal environment giving rise to low speech amplitude, it would be desirable to have a more precise indication of vocal fold activity during the production of Hausa glottalic stops than that given by speech pressure waveforms alone. This would allow us to give a more precise description of the way in which the feature of "laryngealization" may be realized.

4 Few of the early investigators presented data on /ts/ and /ʔ/. It would be desirable to investigate the phonetic nature of these segments and their relationship to the other glottalic segments and the plain segments.

5 Similarly, none of the early investigators presented data on the geminates. It would also be desirable to investigate the phonetic nature of the geminates and their relationship to the single consonants.

## 6.5 The Present Study.

There is a growing interest (cf. chapter 5) in the measurement of voice parameters particularly from those studying the nature of voice in different situations or languages. To achieve this, quantitative measurements have to be made to study the state of voice with a view to capturing any demonstrable change in voice type. The purpose of this work is to present a laryngographic analysis of the activity of the vocal folds in the production of Hausa glottalic and non-glottalic obstruents and /ʎy/ as seen in the speech of several native speakers of Hausa.

## 6.6 The Experiment: Methodology.

### 6.6.1 Instrumentation and Recording.

Two-channel recordings were made in an anechoic room in the Department of Phonetics and Linguistics, University College London. Both digital and analog recordings were made of the speech pressure waveform (Sp) and a laryngographic signal (Lx = Larynx excitation, see chapter 5 section 9.1). The analog recorder was a Uher (160 A.V.), and the digital recorder consisted of a Sony Betamax video recorder (SLF 1) in conjunction with a PCM processor (PCMF 1). Speech was recorded onto the left channel, using a Bruel & Kjaer half-inch pressure-sensitive condenser microphone (Type 4134) in conjunction with a Bruel & Kjaer microphone pre-amplifier (Type 2619). The signal was further amplified using a Bruel & Kjaer measurement amplifier (Type 2610). The Lx signal from the standard portable laryngograph was recorded onto the right channel of the tape recorders (cf. Lindsey et al. 1987:6-7).

The subject was seated in an armchair with a head restraint. The microphone head was positioned at approximately 15cm from his mouth, 10cm from the mid-sagittal line and normal to a plane through and at the height of the informant's lips.

Before the recording, special care was taken to ensure a useful output Lx waveform. The laryngograph electrodes were placed on either side of the thyroid cartilage and waveforms for trial utterances were observed on an oscilloscope. The elastic neck-band used to hold the electrodes in place was not so tight as to cause discomfort to the informant. The recording equipment was in a separate annexe to the anechoic room. There, the speech and Lx signals were monitored over headphones and in addition an oscilloscope was used to display the waveforms during the recording.

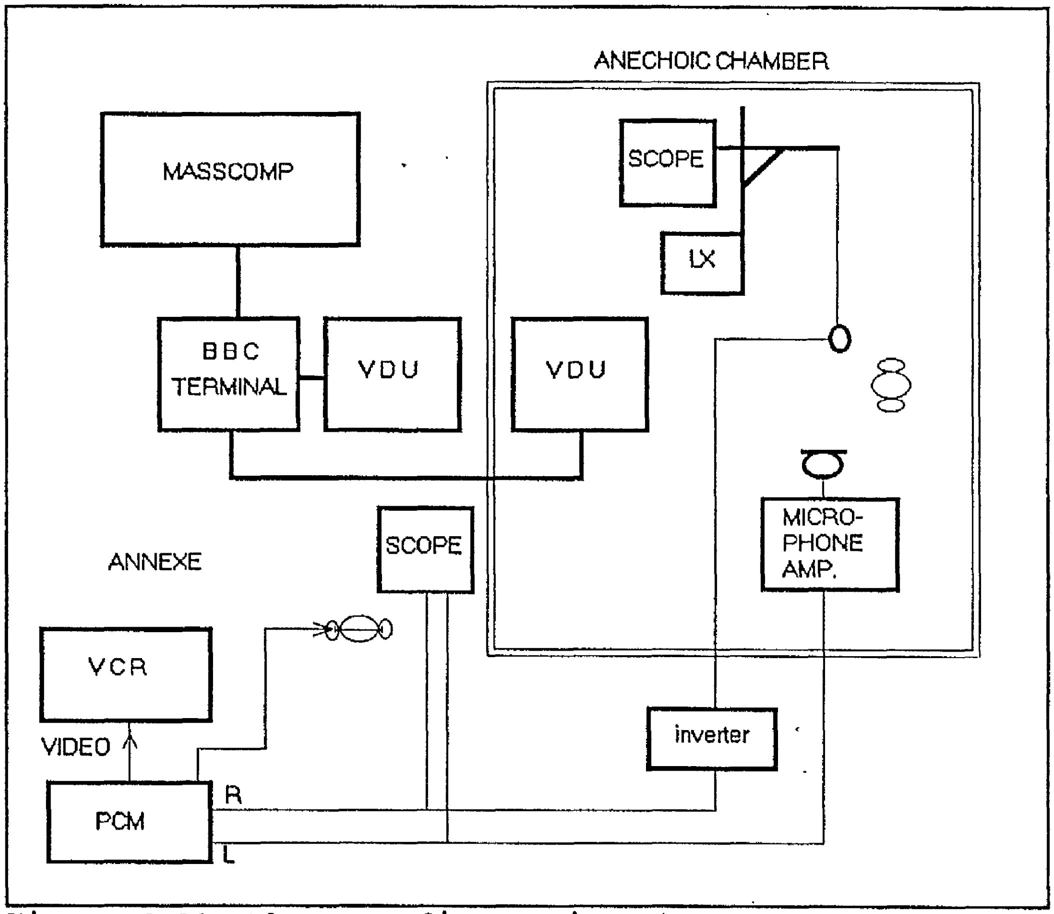



Figure 6.21: The recording equipment.
Source: Lindsey et al. (1987:12).

The informants were instructed to read each word twice. An English gloss was given for each word on the reading list to help avoid wrong reading of tokens. The words were not randomized but read in isolation, at a normal speech rate. A recording session usually lasted ten minutes. A diagram of the complete configuration of equipment is shown in Fig. 6.21.

### 6.6.2 The Laryngograph.

At this stage, it is appropriate to remind ourselves of factors which may make laryngographic analysis unreliable as a record of glottal activity. Problems which typically arise are (cf. section 5.9.2):

1 Possible distortion of voices arising from the equipment, from the informant or due to other practical problems during recording. For example, variation of the capacitance caused by the vibrations of the laryngeal wall or the skin of the throat may affect Lx waveforms.

2 Sometimes it is difficult to place the electrodes in the right place, and sometimes even when they are positioned properly, sudden up and down movement of the larynx may cause displacement of the electrodes.

However, we may have some confidence in the results of the present study because of:

1 The experience of the experimenter, and that of some other regular users of the technique who have in various ways helped in this research, in deriving descriptions of speech mechanisms from laryngograph output. The waveforms were first studied on the computer's visual display and samples of these were printed using a Sperry Laser 37 printer.[1]

2 The Lx waveforms were assessed by reference to illustrations and descriptions of different types of normal Lx waveforms found in the literature.[2]

3 Similarity of Lx waveforms across Hausa speakers. The waveforms of each speaker were compared to see whether there were any marked changes between them. It should be remembered that this is the first major work using a large number of informants to study the nature of the vocal folds during the articulation of Hausa glottalic consonants using the electrolaryngograph.

Previous studies have either used few subjects (e.g. Meyers 1976) or compared Hausa speech pressure waveforms with other languages of different families (cf. Ladefoged 1968 and Lindau 1984).

### 6.6.3 The Material.

The data used in this study is based on East (Kano) Hausa, chosen because it is the standard dialect (cf. section 1.3 for detailed discussion on dialect, and map number 1).

The material consists of tape recordings of plain and glottalic consonants both single and geminate, in intervocalic environment in real Hausa words (cf. Table 6.1), read by sixteen native Hausa speakers. The corpus was restricted to actual words (no nonsense words) for the following reasons:

1 Actual words are generally more likely to be given natural pronunciation than nonsense words;
2 Actual word data facilitates more natural tone patterns and vowel lengths;
3 Informants cannot read phonetic transcription and are likely to be confused by orthographic representation of non-occurring words (cf. Lindsey et al. 1987).

The data was limited to disyllabic words, except the words containing geminates, which have three or more syllables. The words containing the glottalized consonants were read first. Prior to the reading the subjects were told of the content of the task and instructed to read every token. The consonants under investigation occurred:

1 word medially before and after low and high tone (except in the case of plain /y/ and geminates), and
2 usually between two instances of the vowel /a/ (sometimes between other vowels). Each word was

repeated twice by all speakers. Before the actual recording, the subjects had some rehearsal.

All subjects read the data with a high degree of accuracy, and all utterances were accepted as correct renderings, except those spontaneously corrected (either because of wrong tonal pattern or vowel length) by the subject during recording, which were discarded from further consideration. The second reading of each item was chosen for analysis except where an informant made a mistake, in which case the first reading was taken.

The Lx waveforms of words selected for analysis containing the plain and the glottalic consonants in syllable medial position were stored on magnetic tape using a program written by Peter Davies and Mark Huckvale. These waveforms were later analyzed on a Masscomp MC 5600 computer using a program written by Peter Davies (cf. Davies et al. 1986), which gives the cycle-by-cycle open quotient (OQ) of voiced parts of speech. The OQ is the percentage of each glottal period during which the glottis is estimated to be open, using the following definitions:

1 the upper 70% of the peak-to-trough amplitude of each cycle represents glottal closure and
2 the lower 30% represents glottal opening (cf. Davies et al. (1986) for further discussion and other algorithms).

The BBC microcomputer was first used during the preliminary stages of the studies to give enough practice to the experimenter in acquiring waveforms and also to get him acquainted with problems of interpretation. The preliminary work took place at the Phonetics Laboratory SOAS.

## Table 6.1: Word list used in the experiment.

### Bilabial

**Implosive**

sàab'aa = 'shedding of old skin e.g. snake'
sàab'oo= 'grievous sin'
gaab'òo = 'simpleton, fool'
saab'àa = 'disagree'
tab'àa = 'touch'
gaab'àa = 'river bank'
gaab'uu = 'fools'

**Plain**

bàabaa = 'eunuch'
gàabaa = 'enmity'
habà = 'what'
saabàa = 'be used to doing something'
baabìi = 'chapter, category'
gabu = 'cakes of dried and pounded onion leaves, for use when and where onion is scarce'
kabi = 'a horse of a colour between bay and chestnut'

### Alveolar

**Implosive**

fàd'aa = 'say'
kàd'àa = 'stir up'
fad'àa= 'quarrel'
bad'àa = 'sprinkle .. powder'
kwad'ò = 'cold sauce made of pounded groundnuts and various condiments'
kood'àa = 'sharpen blade'
huud'àa = 'ridges'

**Plain**

tsàadaa = 'costliness'
wàadaa = 'dwarf'
faadà ='court of chief'
kadàa = 'crocodile'
huudàa= 'pierce,bore a hole'
k'oodàa = 'kidney'
kwadò = 'a fuel, in brick form, made from the refuse after the oil has been extracted from charred groundnuts'

### Aveolar

**Ejective**

tsòotsoo = 'suck'
gàatsaa = 'bite off'
dàatsaa = 'intercept'
tsaatsàa = 'rust'
daatsàa = 'chop into pieces'
ƭuutsàa = 'worm'
gaatsàa (v.t. with I.O.) 'bite' (something)

**Plain**

suusàa = 'scratch to relieve itch'
taasàa = 'metal bowl'
masà = 'to him'
sòosoo ='loofah sponge, or any sponge'
gàasaa = 'competition'
làasaa = 'lick'

### Velar

**Ejective**

shàak'aa = 'smell,sniff'
tàk'aa = 'pace, stride'
k'òok'oo = 'small calabash'
mak'àa = 'stick or fix'
hak'àa = 'dig'
shâk'àa = 'choke'
mâk'ìi = 'one who distilles slackness'
duuk'àa = 'stoop, bend down'

**Plain**

kàakaa = 'harvest season'
jàkaa = 'bag'
kòokoo = 'cocoa'
hakà = 'thus'
dakàa = 'pound'
duukàa = 'punch, blow'
kooko = 'type of gruel made from soaked guinea-corn flour'

### Glottal Stop

ba?àa = 'joke'
sa?àa = 'one's age-mate, peer'
tà?adii = 'serious damage'
tà?aalaa = 'God the most High'

### Palatal Glide

**Laryngealized**

'yaa'yaa = 'children'

**Plain**

yàayaa = 'gather grass for fodder'
yàayàa = 'how'

### Geminates

**Implosive**

tàb'ab'b'ee = 'the touched one' (masc.)
tàb'ab'b'iyaa = 'the touched one'(fem.)
d'ad'd'àfaa 'to accuse someone falsely'

**Plain**

d'èebabbee = 'the fetched one' (masc.)
d'èebàbbuu = 'the fetched ones' (pl.)
d'èebabbiyaa = 'the fetched one' (fem.)
daddà faa = 'to cook many times'

**Ejectives**

màtsattsee = 'the squeezed one' (masc.)
tsattsàaraa = 'to plan'
sàak'ak'k'ee = 'the woven one' (masc.)
sàak'ak'kiyaa = 'the woven one' (fem.)

**Plain**

cìkakkiyaa = 'the filled one' (fem.)
cìkakkee ='the filled one' (masc.)
tattàaraa = 'to gather'
masassabii = 'harvesting tool'

### 6.6.4 The Informants.

The informants for the main part of the study were sixteen educated native speakers of Hausa, consisting of ten speakers of East (Kano) dialect and six speakers of West (Sokoto) dialect. They were instructed to read the words at the speed of normal conversation. All the subjects were adults, between the ages of 30 and 35 years, including one female (a speaker of West dialect). The subjects were recorded in the anechoic room of the Department of Phonetics, University College London. Only two of them had any formal training in phonetics. Table 6.2 lists the informants. They read the words in the standard variety (East dialect) with a touch of their local accent in the case of the informants who come from other dialect areas. This is the usual widely accepted state of affairs as there is no Hausa equivalent to R.P.

The recordings were made over a period of two years, with no effort to control tempo and speech style. All the sixteen Hausa informants produced single glottalic /b'/, /d'/ and /'y/, plain /b/, /d/ and /y/, but speakers M1 and M5 did not record the ejectives or plain voiceless consonants and speakers M1, M5, M6, M11 and M15 did not record the glottal stop /?/. Not all speakers recorded the geminates as the geminates were not included in the data at the early stages of the recordings. Speakers M1, M5, M6, M9, M11, M13 and F1 (/ss/ for F1) did not record the geminate ejective or plain voiceless consonants, and speakers M1, M5, M9, and M13 did not record /b'b'/ and /d'd'/, plain /bb/ and /dd/ and speaker M6 did not record /d'd'/ and /dd/.

Table 6.2: List of the Informants.

| Informant | Home Town | Place of present residence | Occupation | Date of Recording | Dialect |
|---|---|---|---|---|---|
| M1 | B'ab'ura | Kano | Teacher | 23/6/86 | East |
| M2 | Potiskum | Maiduguri | Teacher | 10/4/87 | East |
| M3 | Had'eja | Sokoto | Teacher | 20/2/87 | East |
| M4 | Bici | Kano | Civil Servant | 20/2/87 | East |
| M5 | Kano | Kaduna | Banker | 20/10/86 | East |
| M6 | B'ab'ura | Lagos | Civil Servant | 12/6/86 | East |
| M7 | Gar | Maiduguri | Teacher | 10/4/87 | East |
| M8 | Zaria | Maiduguri | Teacher | 10/4/87 | East |
| M9 | Kano | Sokoto | Adminis- trator | 8/5/86 | East |
| M10 | Kaduna | Minna | Adminis- trator | 20/2/87 | East |
| M11 | Tsiga | Kano | Teacher | 10/4/87 | West |
| M12 | Sokoto | Sokoto | Teacher | 20/2/87 | West |
| M13 | Sokoto | Sokoto | Teacher | 10/4/87 | West |
| M14 | Sokoto | Sokoto | Teacher | 20/2/87 | West |
| M15 | Kankiya | Kano | Teacher | 23/6/86 | West |
| F1 | Funtuwa | Kaduna | Broadcaster | 20/11/87 | West |

### 6.6.5 Editing Procedure and Segmentation.

In order that measurements taken should be comparable, it was necessary to develop a procedure for segmenting the Lx and speech pressure waveforms. For segmentation purposes it is sometimes very difficult to decide where the consonant ends in the glottalic segments /b'/, /d'/ and /'y/ and the glottal stop /?/. Similarly the voiced stops /b/ and /d/, and the palatal glide /y/, present problems in deciding the beginning and end of the segment. It was not always easy to identify in the waveform the precise start and end of the segment's closure as voicing continues into it from the preceding vowel.

In cases where a sudden decrease in amplitude and change in the shape of the periodic wave could easily be observed, I took this to signal the beginning of the consonant. A corresponding sudden increase in amplitude was noticed at the onset of the following vowel. This was sometimes accompanied by a slight but noticeable presence of noise superimposed on the waveform. The peak of this burst of noise, if present, and the change in shape and amplitude of the waveform were taken to mark the end of the closure. Because of the difficulties in segmentation, my data for the plain voiced stops, the palatal glide and the glottal stop cannot be taken to be as accurate as for the glottalic ones.

For the ejectives, the length of the consonant includes both the burst release and the silent phase immediately following it. These points were reasonably easy to define due to sharp changes in amplitude. To ensure that the segmentation strategies were being consistently adhered to, boundaries were first marked on an expanded waveform using a cursor on the Masscomp computer terminal display screen. The waveforms were consistently and carefully inspected visually and the boundaries of the segments were checked by repeated listening to the sections.

### 6.6.6 Labelling Notations.

Understanding the numbering or labelling system is crucial to the understanding of the measurements. Using software written by Michael Johnson, the waveforms and derived plots for each analyzed word were displayed and hand-labelled at several points in the consonantal environment. The various points identified in the consonantal environment during editing were as follows.

1 **C1** represents the beginning of the consonant.
2 **C2** represents the end of the consonant.
3 **Pre** represents 10 periods of vocal fold vibration (Lx cycles) before the beginning of the consonant (C1).
4 **Post** represents 8 periods after the end of the consonant (C2); when there were no Lx vibrations at this point (due to the shortness of the following vowel as a result of final glottal stop), for the purpose of this study the last Lx cycle in the vowel was labelled as "post".
5 **ON** (onset of voicing) represents reading at the closest point before or after C2 where the reading is possible in those cases where no reading is possible at C2.
6 **OFF** (offset of voicing) represents reading at the closest point before C1 where a reading is possible in those cases where no reading is possible at C1.
7 **B** represents a burst release.
8 **MFo1** Maximum fundamental frequency between pre and C1.
9 **MFo2** Maximum fundamental frequency between C2 and post.

Note: Labels number 8 and 9 are not shown on Fig. 6.22.

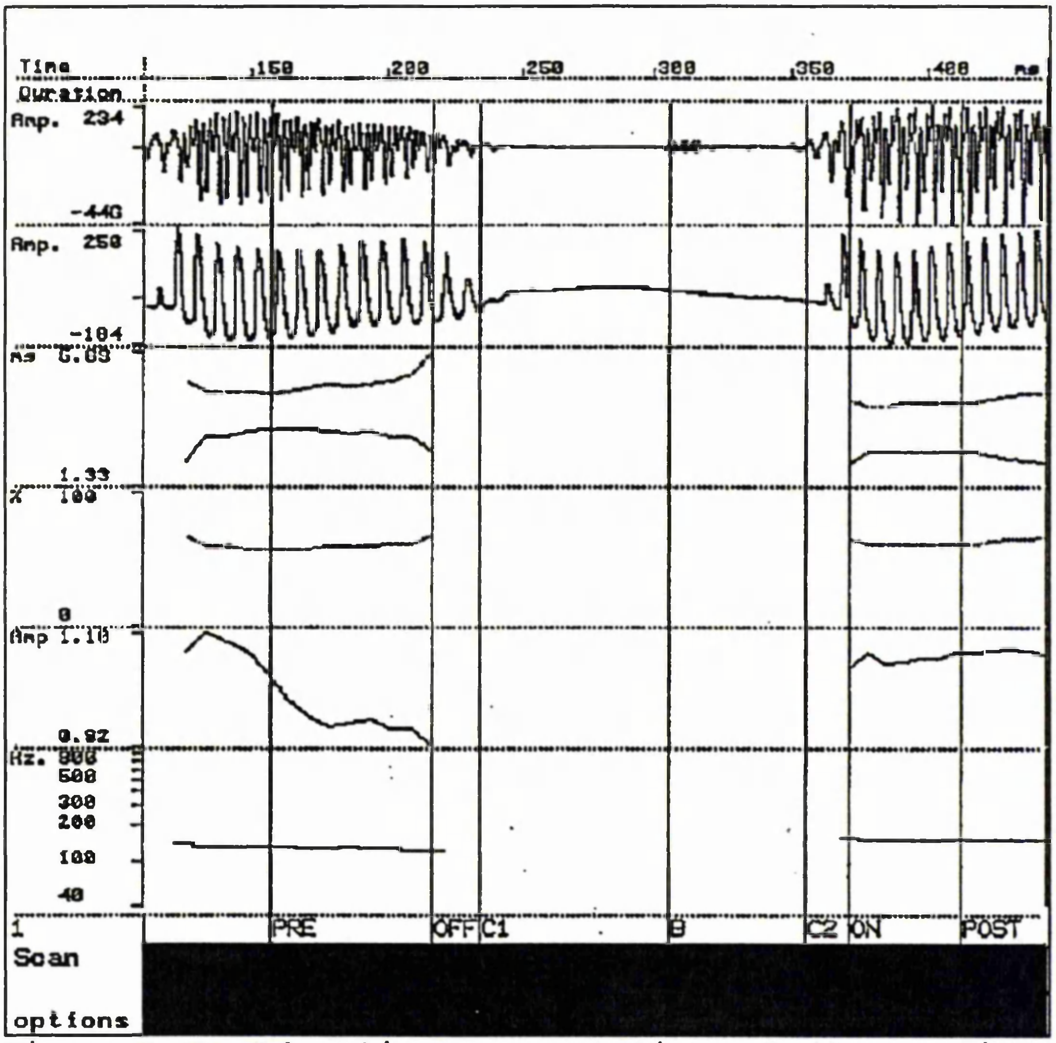


Figure 6.22: Schematic representation of the sections analyzed for each utterance.

Figure 6.22 presents an example showing the plots and segmentation of an utterance [**kòokoo**] 'cocoa' produced by speaker M11 with the sections analyzed identified by the vertical lines. The topmost plot is the speech pressure waveform; below this is the Lx, then the cycle-by-cycle closed phase (solid line) and open phase (dotted line) in milliseconds, plotted on the same axis. It can be seen that, for this utterance by this speaker, the closed phase plot starts to fall while the open phase plot begins to increase as C1 is approached. The OQ is plotted immediately below and is similar to the open phase plot, with a slight increase as we approach C1. The bottom plot is of fundamental frequency, calculated as the reciprocal of the cycle-by-cycle period measured from Lx and displayed on a logarithmic scale. The cursor points are optimally positioned using a "mouse" and cursor controls on the keyboard controlling the computer program.

### 6.6.7 Parameters assessed.

The voice parameters chosen for analysis are the following:

1. Qualitative classification of Lx waveform shapes.
2. Qualitative classification of speech pressure waveforms.
3. Duration of consonant. No attempt was made in the study to control tempo and since there is considerable variation in the data in both word length and phonological vowel length, relatively little can be concluded in this study as to consonant duration. However, the durations, mean durations and the ratio of the duration of matched glottalic-plain consonant pairs has been calculated for each speaker and for all speakers pooled. The duration of the consonants (C1-C2) was measured from the waveform at the offset of the preceding vowel (i.e. at C1) to the onset of the following vowel (C2). The computer program calculated the duration of the interval between the two cursors C1-C2.
4. VOT (voiceless obstruents only). The duration of the VOT of the consonants (B-C2) was measured from the Sp waveform at B to the onset of the following vowel (C2). The computer system calculated the duration of the interval between the two cursors B-C2. The mean VOT duration of the matched glottalic-plain consonant pairs has been calculated for those speakers that recorded the plain voiceless consonants.
5. Open Quotient. The computer system also calculated the

OQ of phonation at the four points in the waveform that the system operator had first marked with the cursors Pre, C1 (or the last Lx cycle before C1), C2 (or the first Lx cycle after C2), and Post. The notation OQpre, OQ1, OQ2 and OQpost is used below to refer to the values of OQ at these four points. The calculated OQ was displayed on the computer screen against the waveform. To minimize the effects of individual speaker differences in OQ range, each OQ measure was normalized in the following way: the average of the four OQ measures in the word **yàayàa** 'how' (which it was assumed would exhibit "modal" voice) was calculated for each speaker, and the OQ measure for all data were divided by the average modal value for the speaker in question, then multiplied by 100 to give a normalized quotient (NQ) (cf. section 6.10.5) for more detailed discussion).

6 Fundamental frequency (hereafter Fo). The computer system calculated the Fo at the four points pre, C1 (or the last Lx vibration before C1), C2 (or the first Lx vibration after C2) and post. The calculated Fo was displayed on the computer system against the waveform. Individual speaker characteristics and the variety of the tonal patterns in the data make the absolute fundamental frequency (or their means) in the environments of the different consonant types rather unrevealing. Because of these difficulties, the method of quantification we adopted was to compare the fundamental frequency at C1 (hereafter Fo1) with MFo1 (maximum Fo between pre and C1) and fundamental frequency at C2 (hereafter Fo2) with MFo2 (maximum Fo between C2 and post) (cf. section 6.10.6 for more discussion on the method of how the data was calculated).

Hard copies were also generated of all the data for visual analysis of the waveforms and plots.

## 6.7 Qualitative Classification of Lx Waveforms: Plain Voiced Stops, Palatal Glide, Laryngealized Stops, Glottal Stop and Laryngealized Glide.

It is more useful to look at Lx waveforms for the laryngealized segments than Sp waveforms, which are better for the ejective and voiceless stops. Four major categories of Lx waveforms have been identified among plain voiced plosives such as /b/, the glottalic consonants /b'/ and /d'/, the glottal stop /?/ and the glottalized palatal glide /'y/. From a qualitative point of view all these segments have similar Lx waveforms. At this point it is also worth mentioning that no consistent significant differences were detected between the Lx waveforms of the glottalic segments /b'/, /d'/ and /?/. The Lx waveforms are categorized according to:

1. their shapes (which are related to the nature of the vocal fold contact), and
2. regularity or irregularity of the vocal fold vibration.

Waveforms for the four types isolated for examination are presented in Figs. 6.23-6.26. Each of these particular examples is taken as representative because it was judged in a visual evaluation of the electrolaryngograph output to be an acceptable prototype of the phonation type in each case, with as few qualifications as possible (cf. below). However, these cannot be presented as definitive waveforms of the four types, as each is only a brief sample of the category in question obtained from one of 16 speakers. Figs. 6.23-6.26 illustrate the complete set of the Lx waveform types identified.

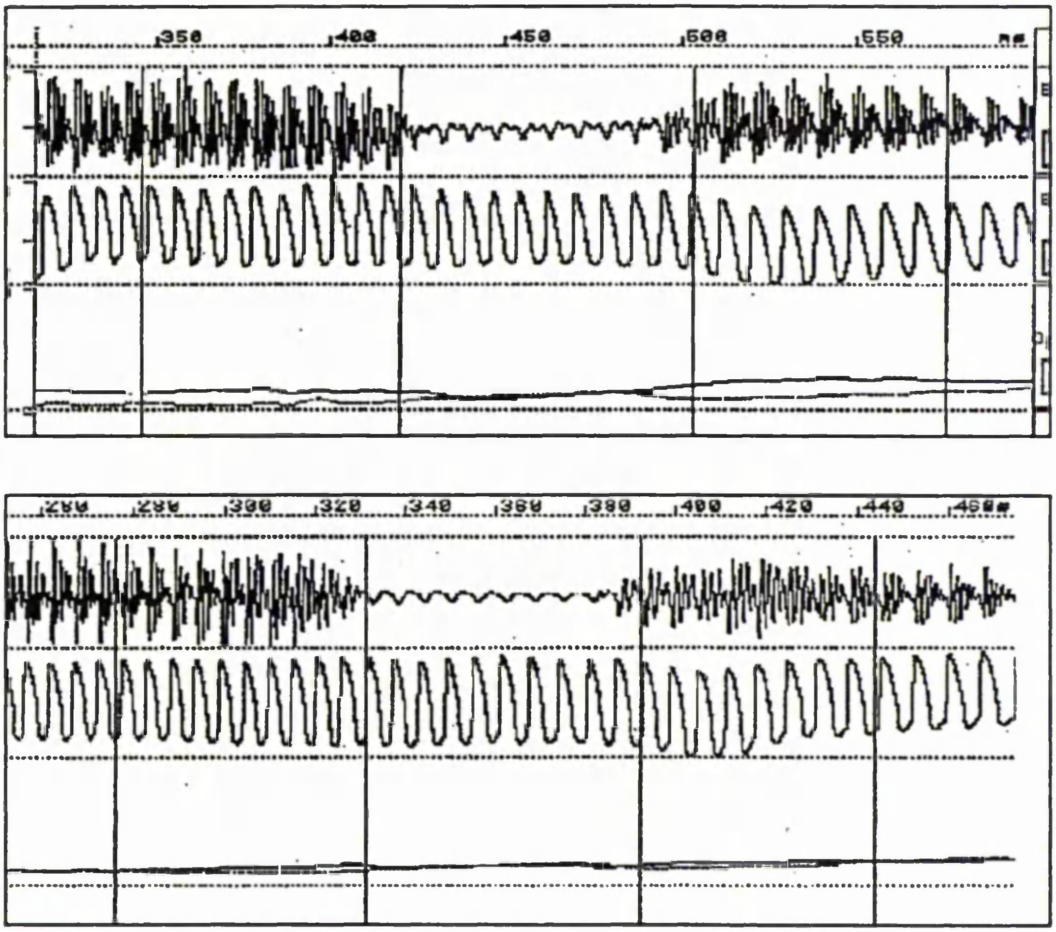



Figure 6.23 (Type 1) shows the waveform of an
(a) intervocalic /b/ produced by speaker M2, **saabàa** and
(b) intervocalic /d/ produced by speaker M4, **faadà.**

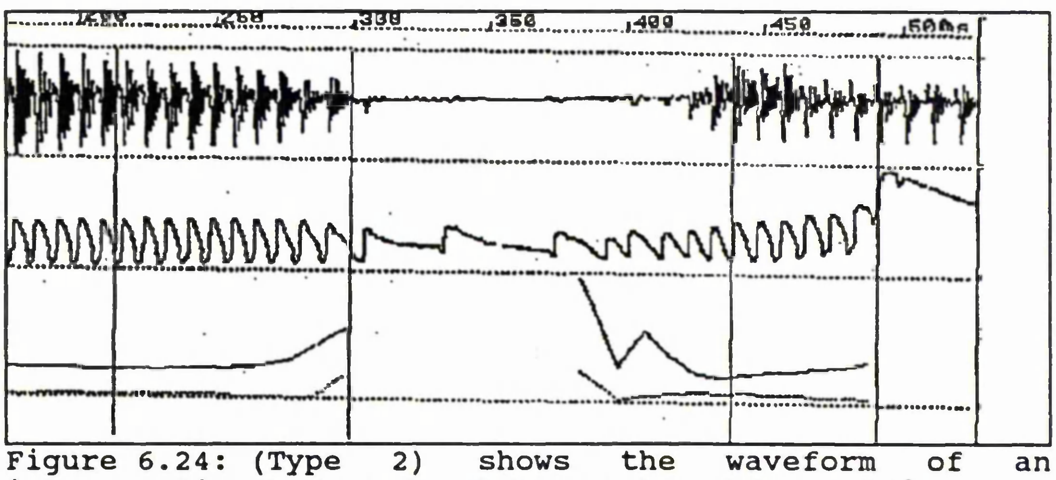



Figure 6.24: (Type 2) shows the waveform of an intervocalic /b'/ produced by speaker M10, **gaab'àa.**

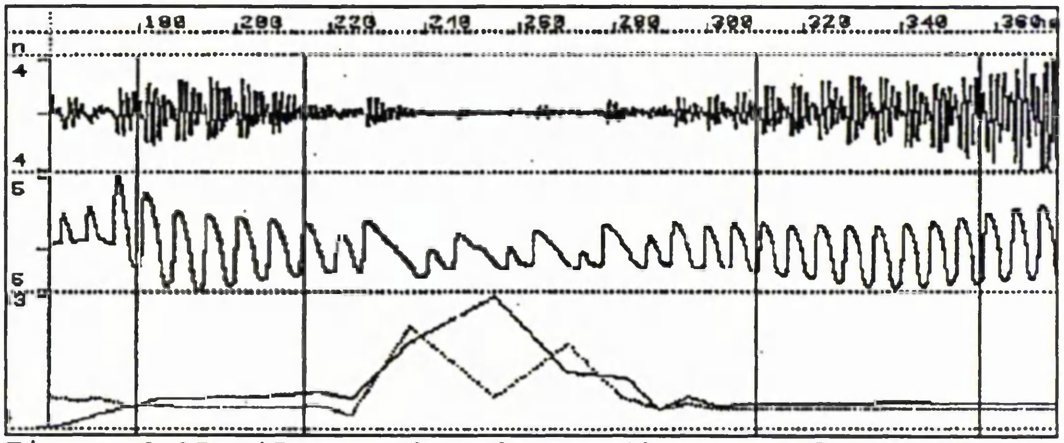


Figure 6.25: (Type 3) shows the waveform of an intervocalic /?/ produced by speaker M4, **tà?adii.**

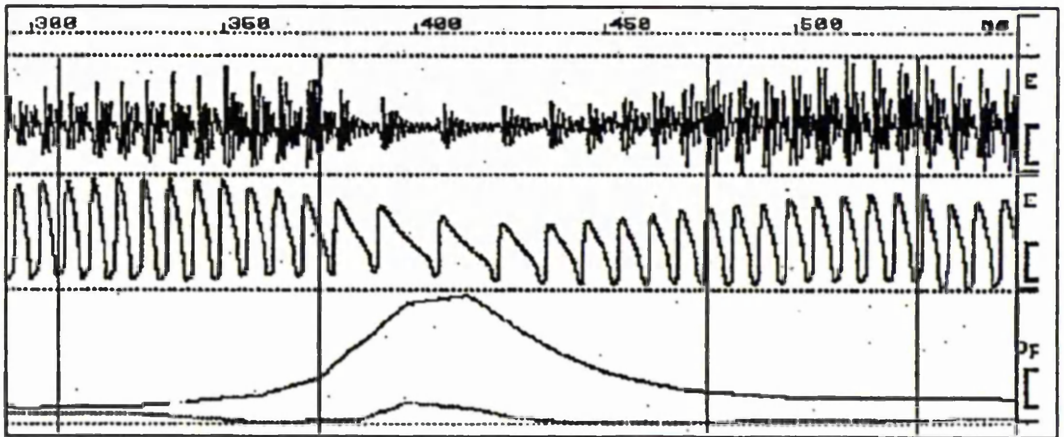


Figure 6.26: (Type 4) shows the waveform of an intervocalic /'y/ produced by speaker M2, **'yaa'yaa.**

**Lx Waveform Type 1.**

The Lx waveform exhibits considerable regularity. The beginning of closure in the Lx waveform is followed by the onset of maximum response from the vocal tract and vibration is maintained in a regular manner throughout the closure period. The Lx waveform shape is regular from one period to another and the closure period is not variable. Both OP (open phase) and CP (closed phase) plots remain in a relatively straight line. The segments that typically illustrate this type of Lx waveform are all the voiced stops and the plain palatal glide. See Fig. 6.27 for typical Lx waveforms of this type.

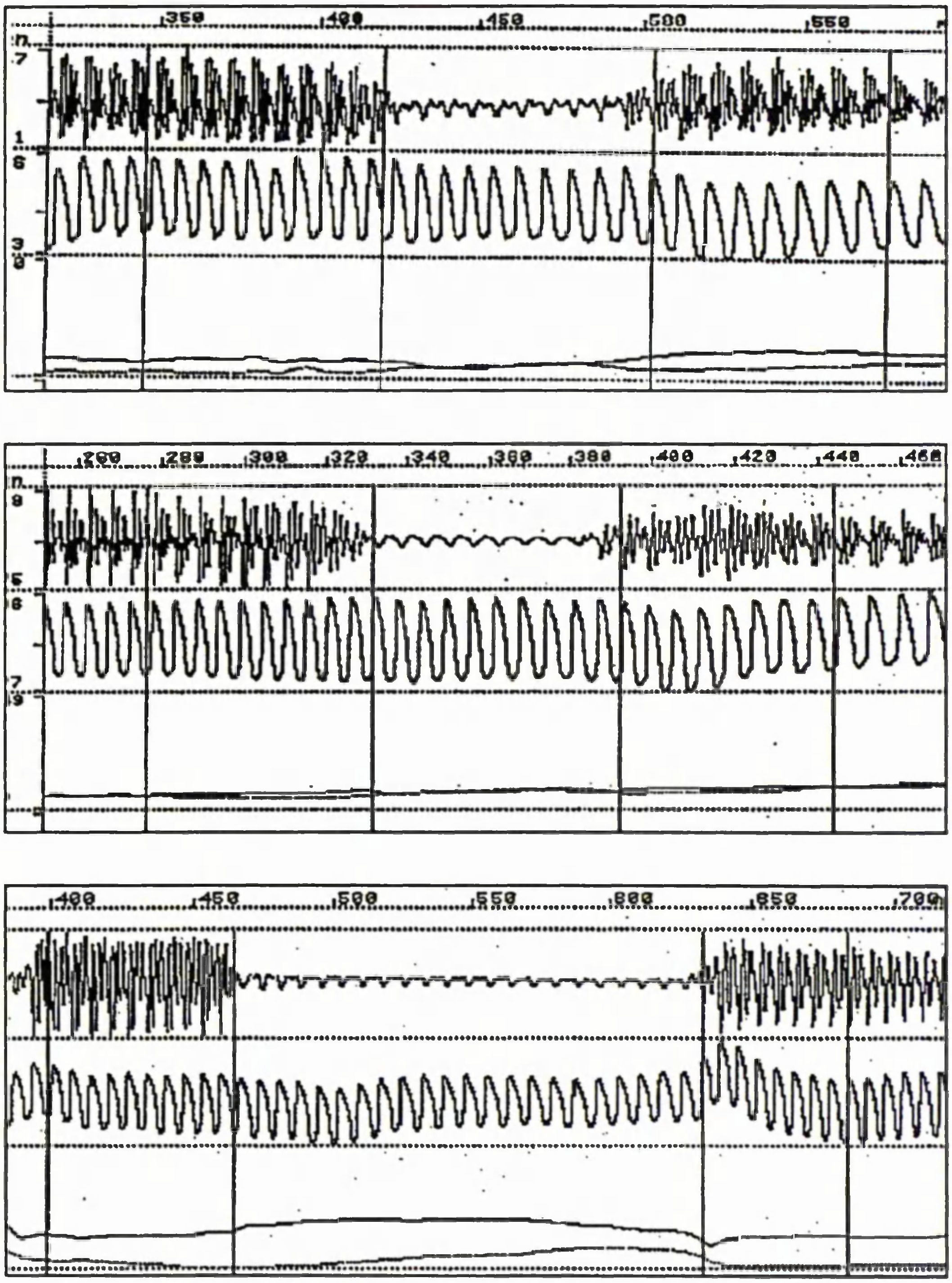



Figure 6.27 (a) shows an intervocalic /b/ produced by speaker M2, **saabàa**, (b) /d/ produced by speaker M4, **faadà** and (c) /bb/ produced by speaker M7, **d'èebabbee.**

**Lx Waveform Type 2.**

In this type there is an increase in closed quotient (CQ) and the Lx waveform shows a particularly long closed phase, longer than in an English "creak". For the entire length of the consonant sometimes only one or two long cycles occur indicating a very long glottal closure, and this is sometimes followed by 2-5 low amplitude cycles before the onset of the following vowel. See Fig. 6.28 for typical Lx waveforms of this type. It can be seen that, for these utterances by these speakers, the closed phase plot increases tremendously just before the beginning and during the occlusion of the consonant then finally decreases abruptly as a more modal phonation is achieved towards the onset of the following vowel at C2. The behaviour of the open phase is very variable. It decreases in Fig. 6.28 (a), stays the same in (b) and increases in (c).

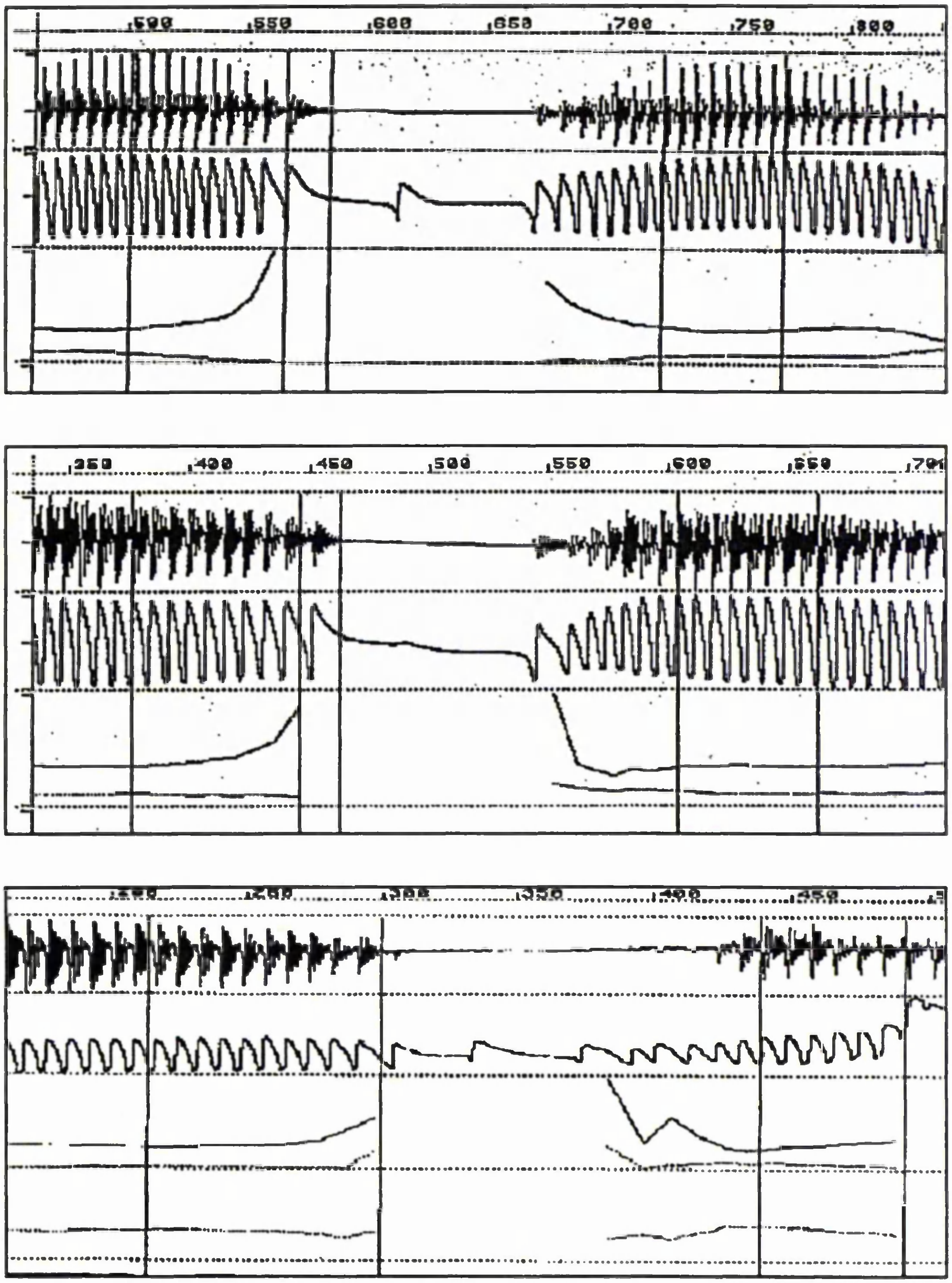



Figure 6.28 illustrates typical Lx waveforms of type 2, produced by (a) speaker M7, **'yaa'yaa**, (b) speaker M10, **'yaa'yaa** and (c) **gaab'àa** produced by speaker M10.

**Lx Waveform Type 3.**

The Lx waveform is usually characterized by irregular vocal fold vibration (i.e. cycle-by-cycle fluctuations in period and waveform shape); sometimes small low amplitude cycles alternate during the consonant with larger cycles of low OQ (cf. Fig. 6.29). The behaviour of the OP is variable. It decreases and then increases in Fig. 6.29 (a), stays low in (b) and increases in (c). As for the CP, it increases in Fig. 6.29 (a & b) and decreases in (c).

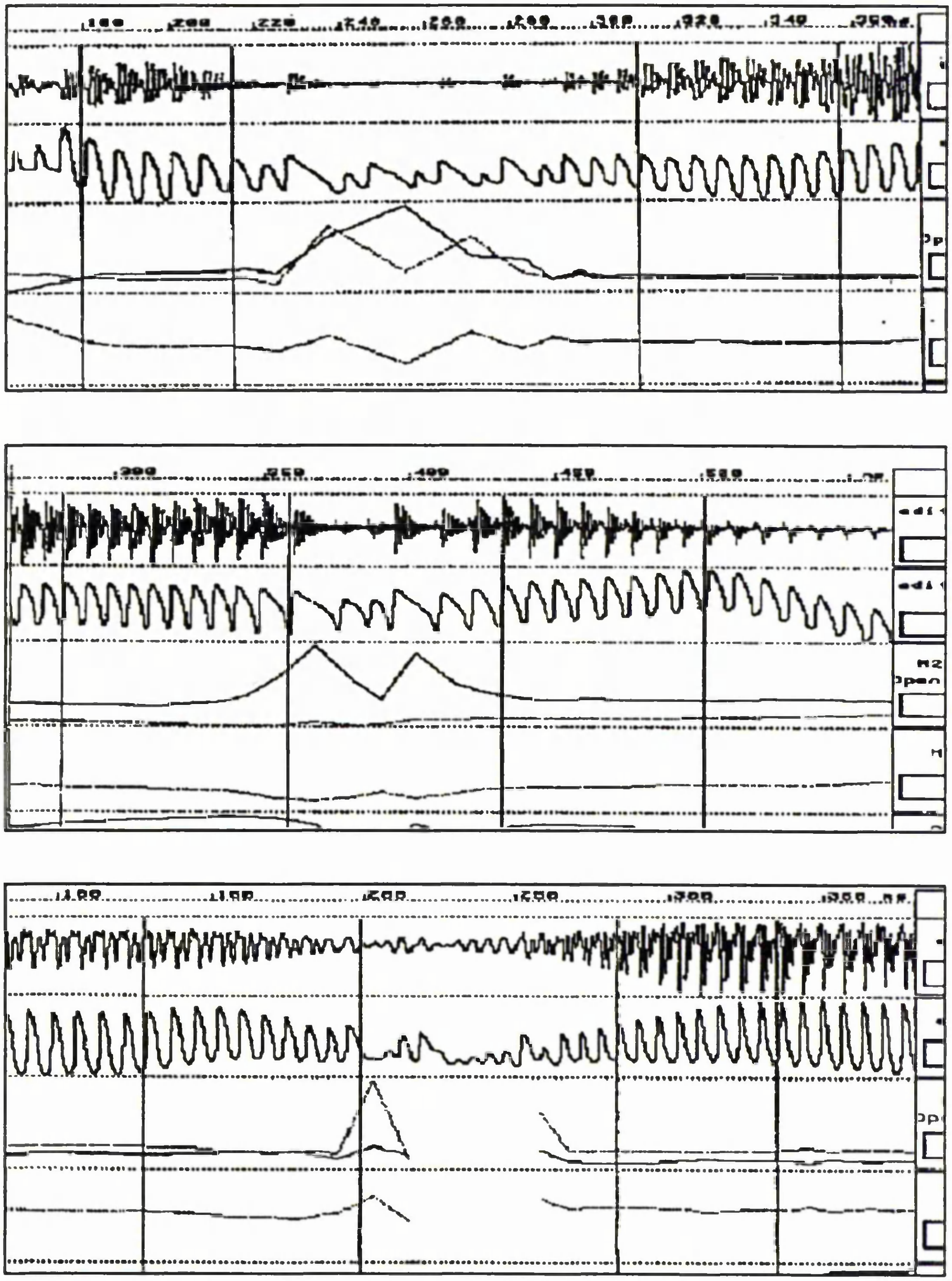


Figure 6.29 shows typical Lx waveforms for type 3, produced by (a) speaker M4, **tà?adii**, (b) speaker M10, **ba?àa** and (c) speaker M11, **huud'àa**.

**Lx Waveform Type 4.**

This category differs from the rest in that, rather than showing irregular alternation of long and short cycles there is a regular vocal fold vibration throughout the consonant, with a smooth (though sometimes rapid) decrease in OP and an increase in CP at the beginning of the consonant (cf. Fig. 6.30).

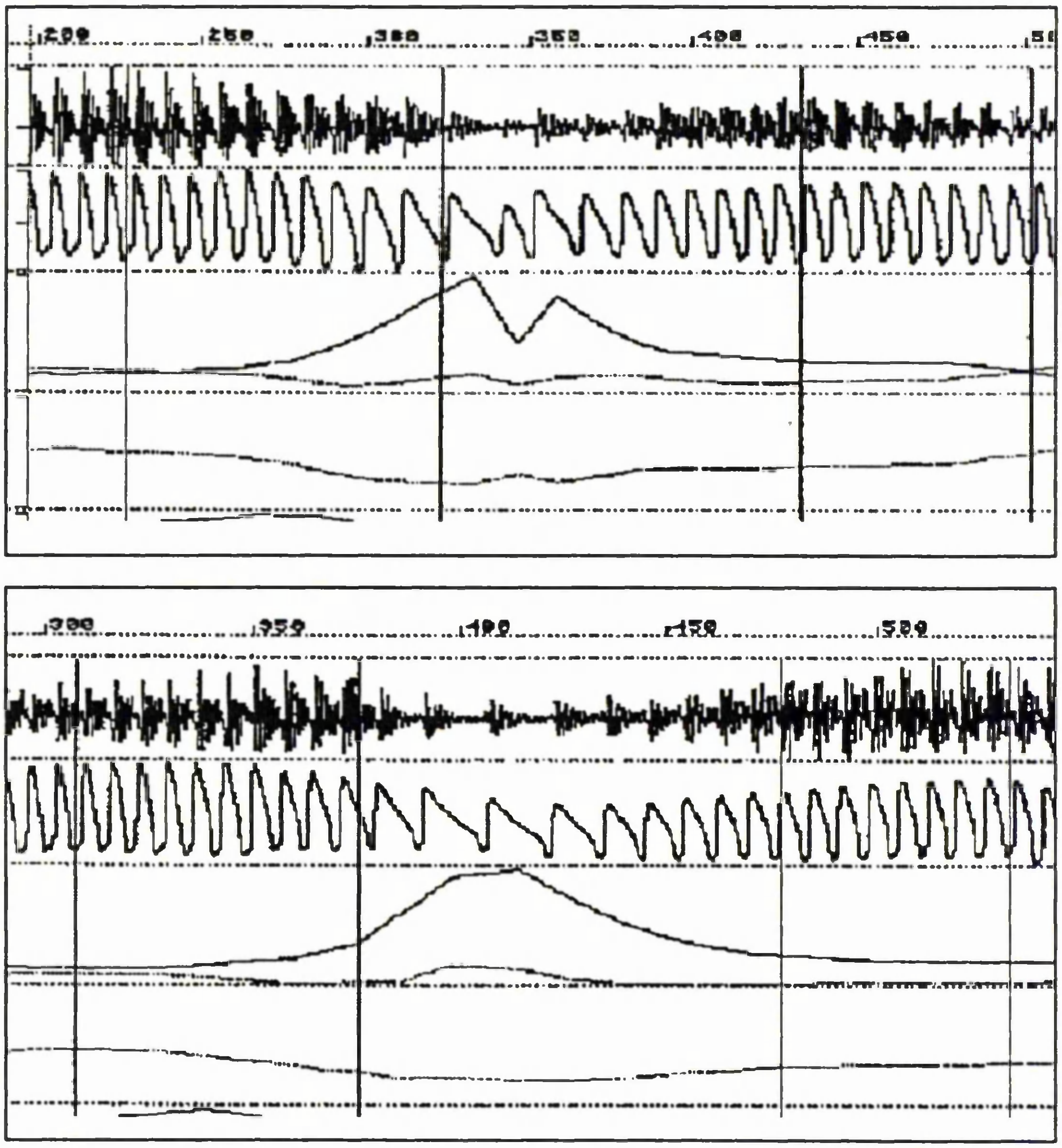



Figure 6.30 shows typical Lx waveforms for type 4, produced by (a) speaker M1, **'yaa'yaa** and (b) speaker M2, **'yaa'yaa.**

It is possible to see a mixture of Lx waveform types 2-4. See Fig. 6.31 which shows a typical Lx waveform of this type. A general decrease in fundamental frequency and OQ is discernible, but some irregularity is also present, including a particularly long cycle. The behaviour of the OP is variable. It decreases and then increases in Fig. 6.31 (a), decreases in (b) and increases in (c). The CP increases in all three cases Fig. 6.31 (a-c).

Having established the differences between the waveforms, it is worth noting the similarities between them. Lx waveform Types 2, 3, and 4 are not completely dissimilar as all three involve several vibrations with progressive decrease in OP and increase in CP most of the time. They are all associated with the segments /b'/, /d'/ and /'y/ which are phonologically defined in the same way even though they are phonetically different, as all are points on a continuum from "long glottal stop" to "a series of creaky cycles".

It is worth noting that the general pattern in these three Lx waveform types associated with the glottalic (laryngealized) stops and the palatal glide applies in my data to the glottal stop segment as well. Ladefoged (1968:17) points out that "it is often not possible to make an absolute distinction between laryngealization and glottal closure; as in the case of so many other phonetic oppositions there is an infinite gradation between the poles of the two categories". He cites the case of syllable-final glottal reinforcement of voiceless stops in RP English, "in which the movements of the vocal folds become slower and slower so that the last one, in which the vocal folds are held together for an appreciable length of time, might well be called a glottal stop" (p.17), cf. Fig. 6.33 and 6.34). It is also interesting to see that all the various changes or differences between the consonant types happened at C1 rather than at C2. This is further supported by the quantitative analysis in section 6.10.

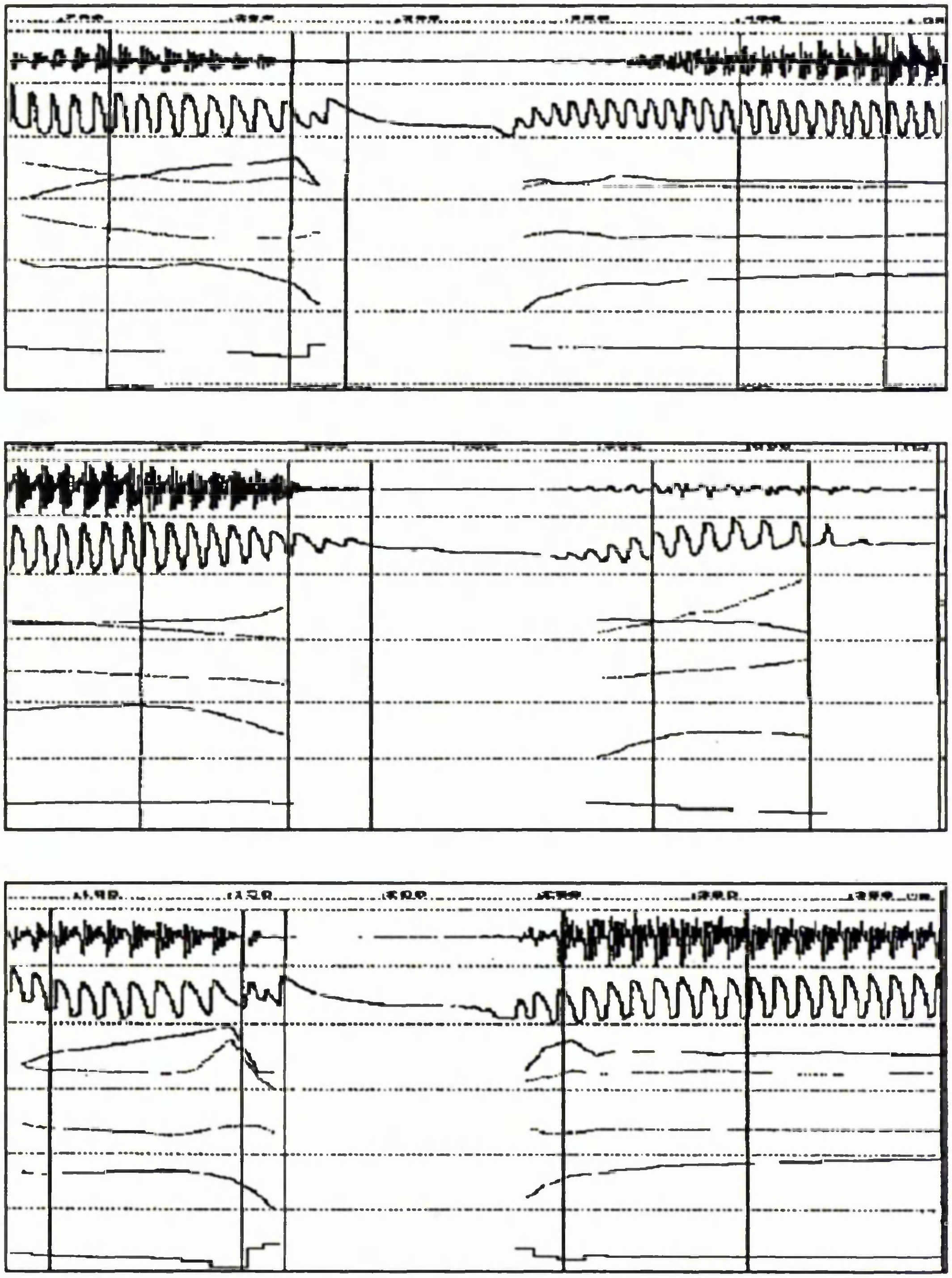


Fig.6.31 shows illustrations of a mixture of Lx types 2-4, produced by (a) speaker M4, **fàd'aa**, (b) speaker M6, **gaab'òo** and (c) speaker M10, **fàd'aa**.

## 6.8 Qualitative Analysis: Results and Discussion.

### 6.8.1 Introduction.

In this section the waveforms of the individual segments are discussed based on the categories set up above.

### 6.8.2 /b'/ and /d'/ vs /b/ and /d/.

#### 6.8.2.1 Description of Lx and Sp waveforms.

Investigating phonation type, Meyers (1976) reports that "during the initial portion of the oral closure there are two or three oscillations that may be vibrations of the vocal cords occurring at irregular intervals as in laryngealized voice" (1976:20); and of the eleven recordings made of /b'/ (by a single speaker) in intervocalic position, "none had voicing for a considerable time before release of the articulation of the segment". Similarly Lindau (1984) observed that five of her fourteen speakers "produced a voiceless beginning of the closure, presumably from a glottal closure as the larynx descends" (1984:151). The remaining nine of her speakers produced a closure which "displays highly aperiodic vibration" (1984:151). Lindau suggests that the aperiodic vibration was "due to noise from incomplete closures in the vocal fold vibrations, and possibly also due to noise generated by perturbations of the vocal tract walls as the larynx descends" (1984:151-2).

In my data the general picture that emerges suggests that the glottalic /b'/ and /d'/ cannot be divided into "partially voiceless" and "irregularly voiced" as implied by the earlier studies above (cf. Haruna and Lindsey forthcoming); instead the Lx waveforms show a gradual change in shape as the waveform phase lengthens before returning to a more "modal" voice for the following vowel.

See Fig. 6.32 which shows examples of Sp and Lx waveforms for the plain and the glottalic bilabial and alveolar stops.

During the initial portion of the glottalic consonants there is an increased closed quotient value as the vocal folds come together for a very long cycle (cf. the CP plot in Fig. 6.32 (b & d)). It is also easy to see on the Lx waveforms that the plain and the glottalic stop types differ with regard to the rate of vibration of the vocal folds. At the onset of the consonants /b'/ and /d'/ there are one or two long cycles (on the Sp waveforms there is no speech pressure for this length of time); then, when the vocal folds do start vibrating, there are several fairly regular recurring cycles of vibrations during the first part of the following vowels.

My data also suggest that there is considerable variability in the occurrence of waveform types 2, 3 and 4 (or a combination) in the Hausa glottalic consonants, although the geminate stops appear to favour Lx waveform type 2, with one or two particularly long cycles. This suggests that a "true" glottal stop may be the target in the glottalic consonants but that it is achieved only given a sufficiently long consonant duration.

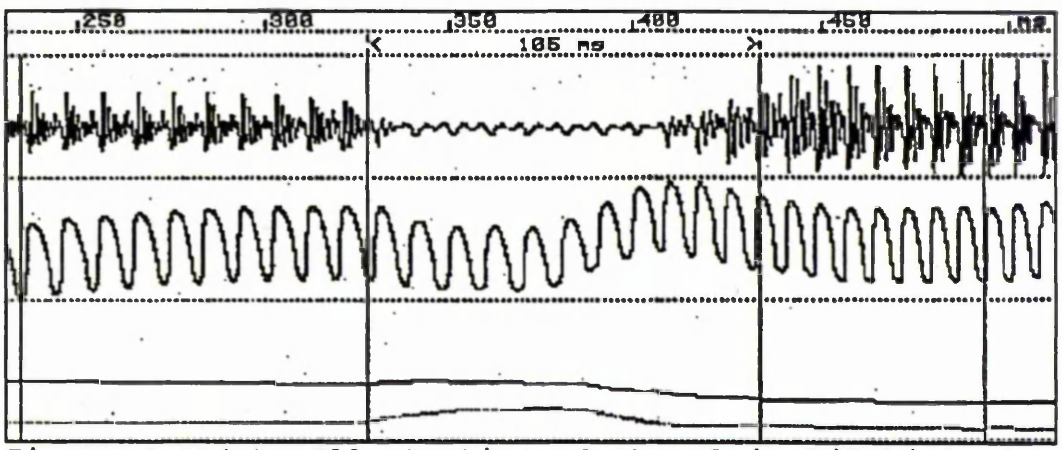


Figure 6.32(a): Illustration of the plain bilabial stop /b/.

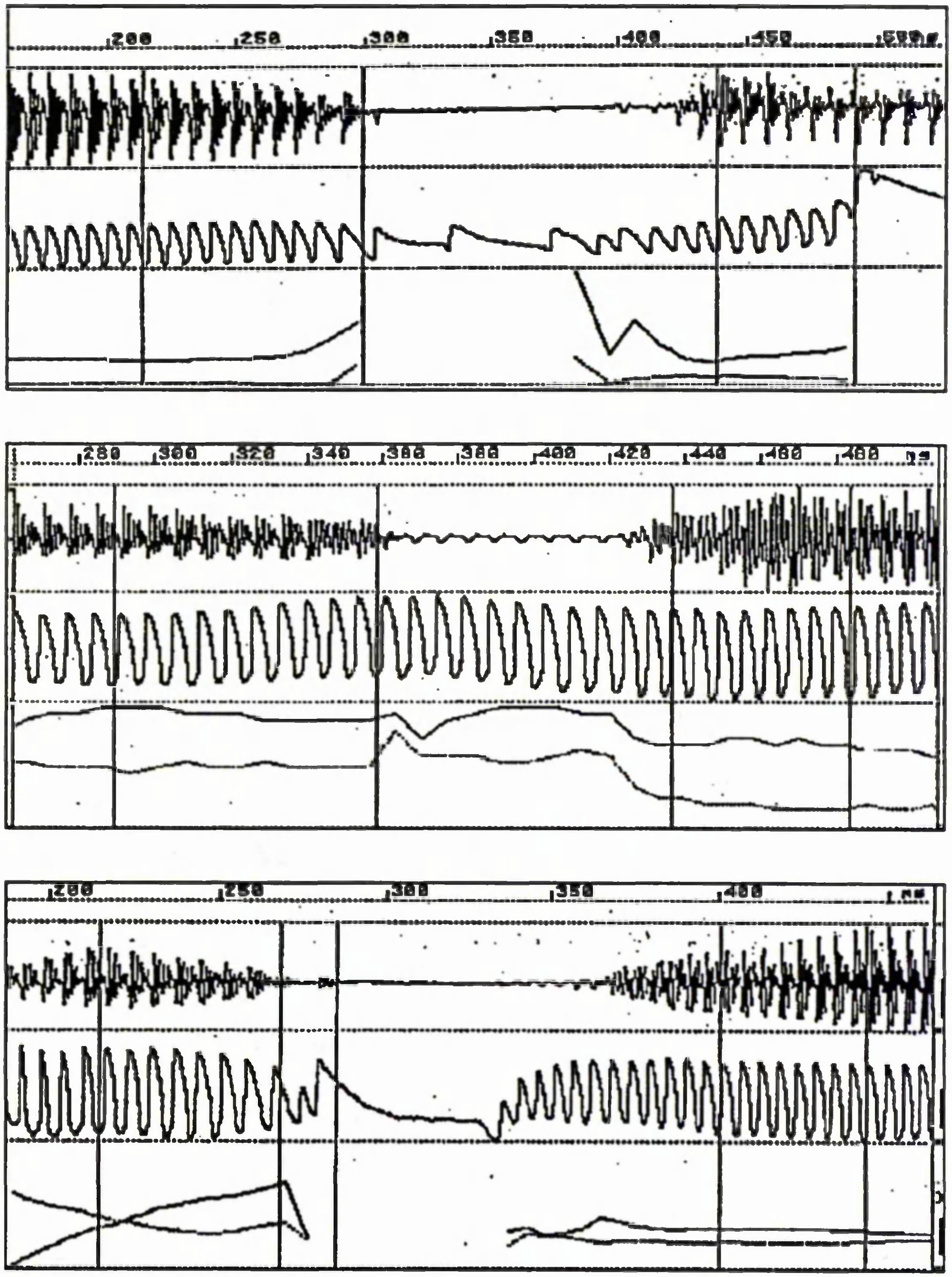


Figure 6.32 (b-d): Illustrations of (a) the plain bilabial stop /b/ and (b) the glottalic bilabial stop /b'/, produced by speakers M7, **bàabaa**, and M10, **gaab'àa**, (c) the plain alveolar stop /d/ and (d) the glottalic alveolar stop /d'/ produced by speaker M4, **tsàadaa** and **fàd'aa**.

It is further noticeable from the waveforms and to some extent from auditory analysis that

1 the longest cycles occur during the consonant;
2 the greatest drop in OQ is near to the start of the consonant; and
3 the effect of some of the glottalic consonants on phonation type is greater at the start than at the end of the consonant (cf. Haruna and Lindsey and Lindsey et al. forthcoming).

This is in agreement with Meyers' observation noted above and contrasts with the statement of Ladefoged (1975:24) that in the glottalized stops of "Hausa and many West African languages ...the creaky voice is most evident not during the stop closure itself but during the first part of the following vowel" (it seems he was talking about perceptual characteristics of the glottalic consonants although this was not categorically stated). As for the non-glottalic voiced stops both waveforms show periodic vibrations of the vocal folds throughout the duration of the consonants.

However, the data show much variation between speakers for the two places of articulation (bilabial and alveolar), although each speaker was found to be consistent if asked to pronounce the token twice more. For the glottalic bilabial stop two tokens were read by each of 16 speakers. It was found that 7 speakers out of the 16 produced Lx waveform Type 2 for both tokens (one speaker M1 read only one token), 4 speakers produced Lx Type 4 for both tokens, 3 other speakers each produced one Lx Type 2 and one type 4 for the two tokens, one produced one each of Lx Types 3 and 4 and the other produced one each of Lx Types 2 and 3 (cf. Table 6.3).

As for the alveolar glottalic consonant /d'/, 15 speakers read 2 tokens each: 4 out of the 15 speakers produced Lx waveform Type 2 for both tokens, 4 produced Lx Type 4, and 2 produced Lx Type 3 for both, and of the remaining 5 speakers 2 produced one each of Lx Types 2 and 4, 2 produced Lx Types 3 and 4 and 1 produced Lx Types 2 and 3 (cf. Table 6.3).

There is no variation in the geminates. All speakers produced Lx waveform Type 2 all of the time.

Table 6.3: Breakdown of variation according to speaker and between speakers for /b'/ and /d'/.

| Speakers | Tokens read Bilabial | Lx Patterns T1 | T2 | T3 | T4 | Tokens read Alveolar | Lx Patterns T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|---|---|---|---|---|
| M1 | 1 | - | 1 | - | - | - | - | - | - | - |
| M2 | 2 | - | 1 | - | 1 | 2 | - | - | 1 | 1 |
| M3 | 2 | - | 2 | - | - | 2 | - | 2 | - | - |
| M4 | 2 | - | 2 | - | - | 2 | - | 2 | - | - |
| M5 | 2 | - | 2 | - | - | 2 | - | 2 | - | - |
| M6 | 2 | - | 2 | - | - | 2 | - | 1 | 1 | - |
| M7 | 2 | - | 2 | - | - | 2 | - | - | - | 2 |
| M8 | 2 | - | 1 | - | 1 | 2 | - | - | 2 | - |
| M9 | 2 | - | - | 1 | 1 | 2 | - | 1 | - | 1 |
| M10 | 2 | - | 1 | - | 1 | 2 | - | 1 | - | 1 |
| M11 | 2 | - | - | - | 2 | 2 | - | - | - | 2 |
| M12 | 2 | - | - | - | 2 | 2 | - | - | - | 2 |
| M13 | 2 | - | - | - | 2 | 2 | - | - | - | 2 |
| M14 | 2 | - | 1 | 1 | - | 2 | - | - | 2 | - |
| M15 | 2 | - | - | - | 2 | 2 | - | - | 1 | 1 |
| F1 | 2 | - | 2 | - | - | 2 | - | 2 | - | - |
| Total | 31 | | 17 | 2 | 12 | 30 | | 11 | 7 | 12 |

### 6.8.3 /'y/, /?/ and /y/.

It is important to note that previous studies did not provide any data on the glottal stop or include it for comparison (except Meyers (1976) who only compared the Sp waveforms of the segments).

Ladefoged (1968), Meyers (1976) and Lindau (1984) provide a fuller attempt at describing the phonetic nature of /'y/. In his book Ladefoged points out that "It is often not possible to make an absolute distinction between laryngealization and glottal stop" (Ladefoged 1968:17). He cites the case of syllable-final glottal reinforcement of voiceless stops in RP English (cf. section 6.7 above). Compare Fig. 6.33 which shows the end of the vowel in **eight** produced by a female speaker of RP, and Fig. 6.34 for Hausa /'y/ produced by speaker M2, **'yaa'yaa**. The Lx waveform is very similar and the degree at which the glottis is open for each successive cycle decreases accordingly. In fact, the Lx waveform shown in Fig. 6.34 is just one of several typical waveforms identified for /'y/; see section 6.7 where others are given.

Figure 6.33: Speech and laryngograph waveforms at the end of the vowel in **eight**, with cycle-by-cycle OQ.

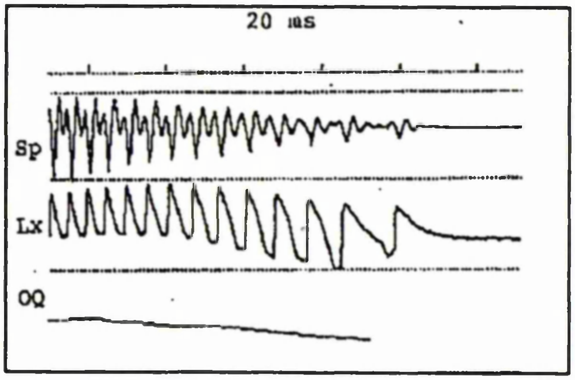
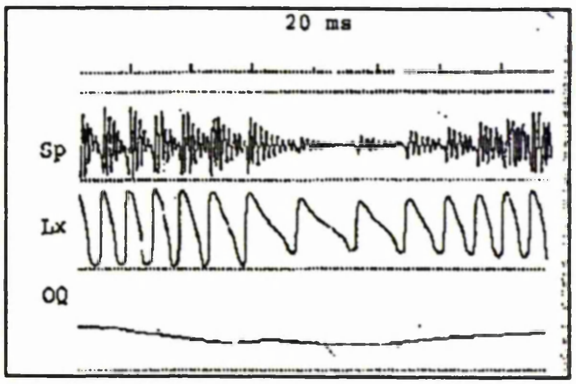



Figure 6.34: Speech and laryngograph waveforms for Hausa /'y/ with OQ.




6.8.3.1 **Description of the Lx waveforms.**

My data show a similar pattern of activity to that described in previous investigations (see section 6.3). See

Figs. 6.35, 6.36 and 6.37 which show /'y/ produced by speaker M7, **'yaa'yaa**, with /ʔ/ produced by speaker M8 and /y/ produced by speaker M10 which are presented for comparison. In Fig. 6.35 the Lx waveform for the glottalic /'y/ shows a sudden change from normal voicing to something like a glottal stop, followed by 2 or 3 low amplitude cycles, the glottal stop occurring some milliseconds before the change back to normal voicing. The OP and CP plots show a decrease in OP with an increase in CP.

However, the recordings differed between speakers as seen from the Lx waveforms. 16 speakers each read one token. 11 produced /'y/ with initial voicelessness (cf. Lx waveform type two, Fig. 6.28 for this category of /'y/), 1 speaker produced it with vibration all through with decreasing Fx and OQ and 4 speakers produced it with a characteristic of creaky voice (cf. Fig. 6.30).

In Fig. 6.36 we find an example of an Lx waveform for the glottal stop. It can be seen that it looks very similar to the one found for the glottalic palatal glide, see Fig. 6.35. At the initial part of the segment there is a long period of closed phase (glottal stop) (see CP plot which shows a big increase), and just before transition into the following vowel there are 1 or 2 irregular cycles.

The recordings of the /ʔ/ also differed greatly from speaker to speaker. 11 out of the 16 speakers read 21 tokens. Of this number 3 speakers consistently produced Lx waveform type 2, 2 produced type 4; 4 speakers each produced one Lx waveform type 2 and one type 4, and the other 2 each produced one Lx type 2 and one type 3 (cf. Table 6.4). Fig. 6.37 shows the palatal glide /y/, produced by speaker M10, **yàayàa**. We can see that it is voiced throughout.

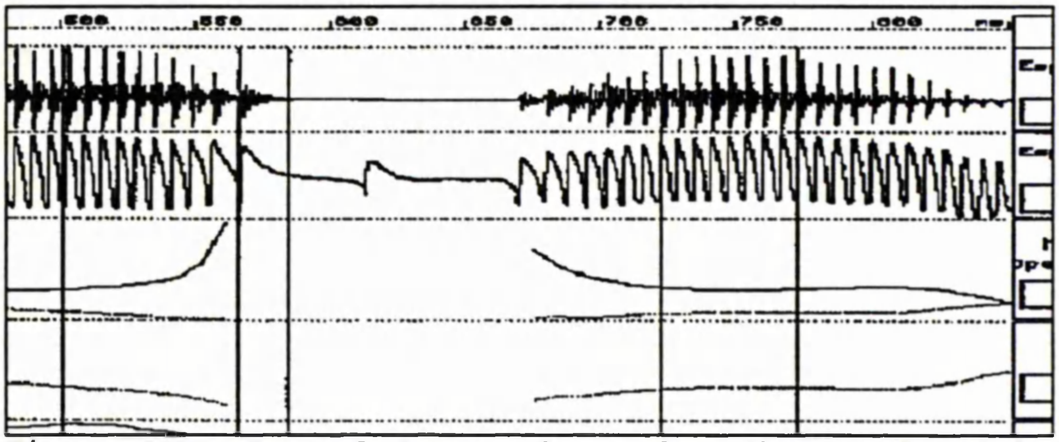


Figure 6.35: Lx and Sp waveforms for /'y/ produced by speaker M7, **'yaa'yaa**.

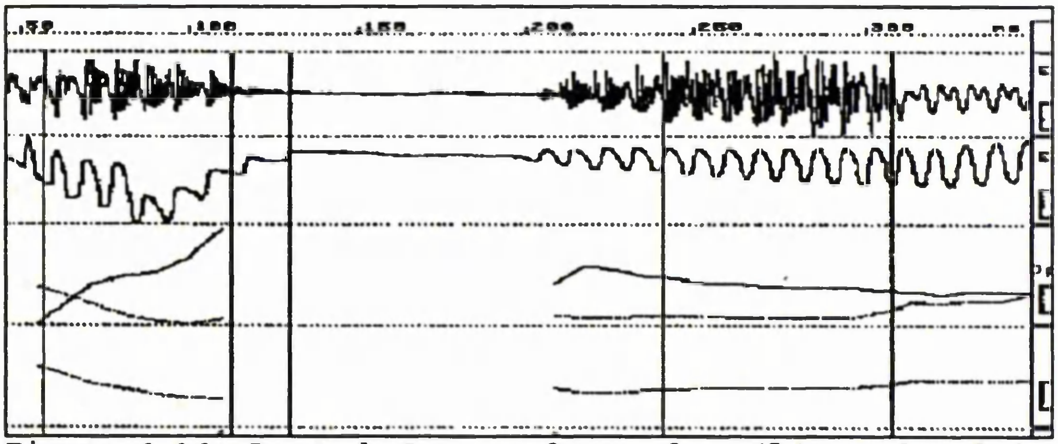


Figure 6.36: Lx and Sp waveforms for /?/ produced by speaker M8, **tà?adii**.

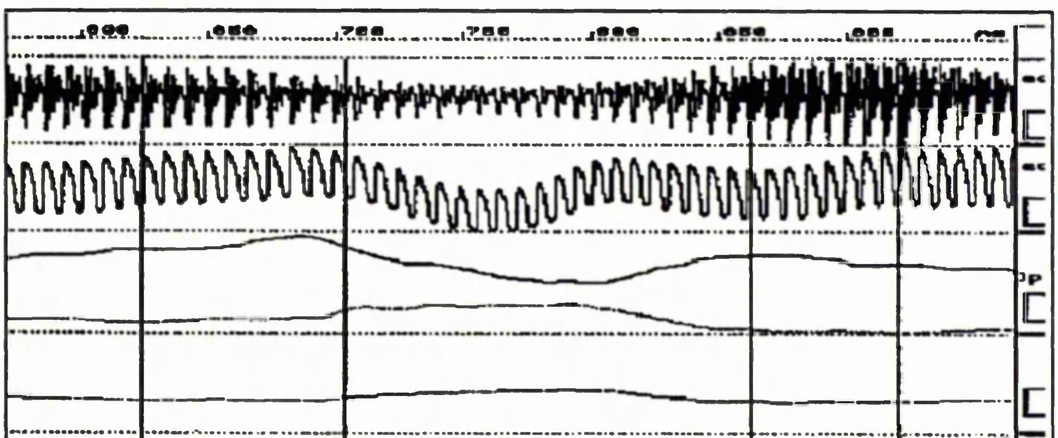


Figure 6.37: Lx and Sp waveforms for /y/ produced by speaker M10, **yàayàa**.

Table 6.4: Breakdown of variation according to speaker and between speakers for /'y/ and /?/.

| Speakers | Tokens read | Lx Patterns | | | Tokens read | Lx Pattern | | |
|---|---|---|---|---|---|---|---|---|
| | /'y/ | T2 | T3 | T4 | /ʔ/ | T2 | T3 | T4 |
| M1 | 1 | - | - | 1 | - | - | - | - |
| M2 | 1 | - | - | 1 | 2 | 1 | - | 1 |
| M3 | 1 | 1 | - | - | 2 | - | - | 2 |
| M4 | 1 | 1 | - | - | 2 | 1 | - | 1 |
| M5 | 1 | 1 | - | - | 1 | 1 | - | - |
| M6 | 1 | 1 | - | - | - | - | - | - |
| M7 | 1 | 1 | - | - | 2 | 2 | - | - |
| M8 | 1 | 1 | - | - | 2 | 1 | 1 | - |
| M9 | 1 | - | - | 1 | 2 | 1 | 1 | - |
| M10 | 1 | 1 | - | - | 2 | 1 | - | 1 |
| M11 | 1 | 1 | - | - | - | - | - | - |
| M12 | 1 | 1 | - | - | - | - | - | - |
| M13 | 1 | 1 | - | - | 2 | - | - | 2 |
| M14 | 1 | - | 1 | - | 2 | 1 | - | 1 |
| M15 | 1 | - | - | 1 | - | - | - | - |
| F1 | 1 | 1 | - | - | 2 | 2 | - | - |
| Total | 16 | 11 | 1 | 4 | 21 | 11 | 2 | 8 |

## 6.9 Qualitative Classification of Sp Waveforms: Ejectives and Voiceless Stops.

It is most useful to look at Sp waveforms in studying the ejectives and the voiceless stops. The speech pressure waveforms have been classified according to the onset and offset of a given acoustic event (e.g. burst) within them. Four types of waveforms have been identified as follows.

### Sp Waveform Type 1.

In the speech display of type 1 the consonant between vowels appears as C1 (beginning of consonant) followed by a gap or silent period with no noticeable noise, then a burst (B) of relatively high amplitude (more than the kind noticed in type three below), followed by another silent period with no noticeable noise before C2, and then the onset of the following word. (The second silent period should probably be identified as a continued glottal stop after the velar release; Greenberg pointed out that with ejectives "as is often pointed out in the literature, the glottal occlusion is normally released after the oral occlusion" (Greenberg 1970:254)).

The waveform of the burst release, which is usually of high amplitude at the start, decreases gradually in amplitude towards the end of the release period. The beginning of the vowel following the stop release is characterized by a comparatively low amplitude with a continuously changing pattern which then becomes stable (compare vowels after type 2 stops below). The stop typically associated with this category is the ejective /k'/. See Fig. 6.38 which is a display of the digitized waveforms of an ejective stop /k'/ between two vowels /a/.

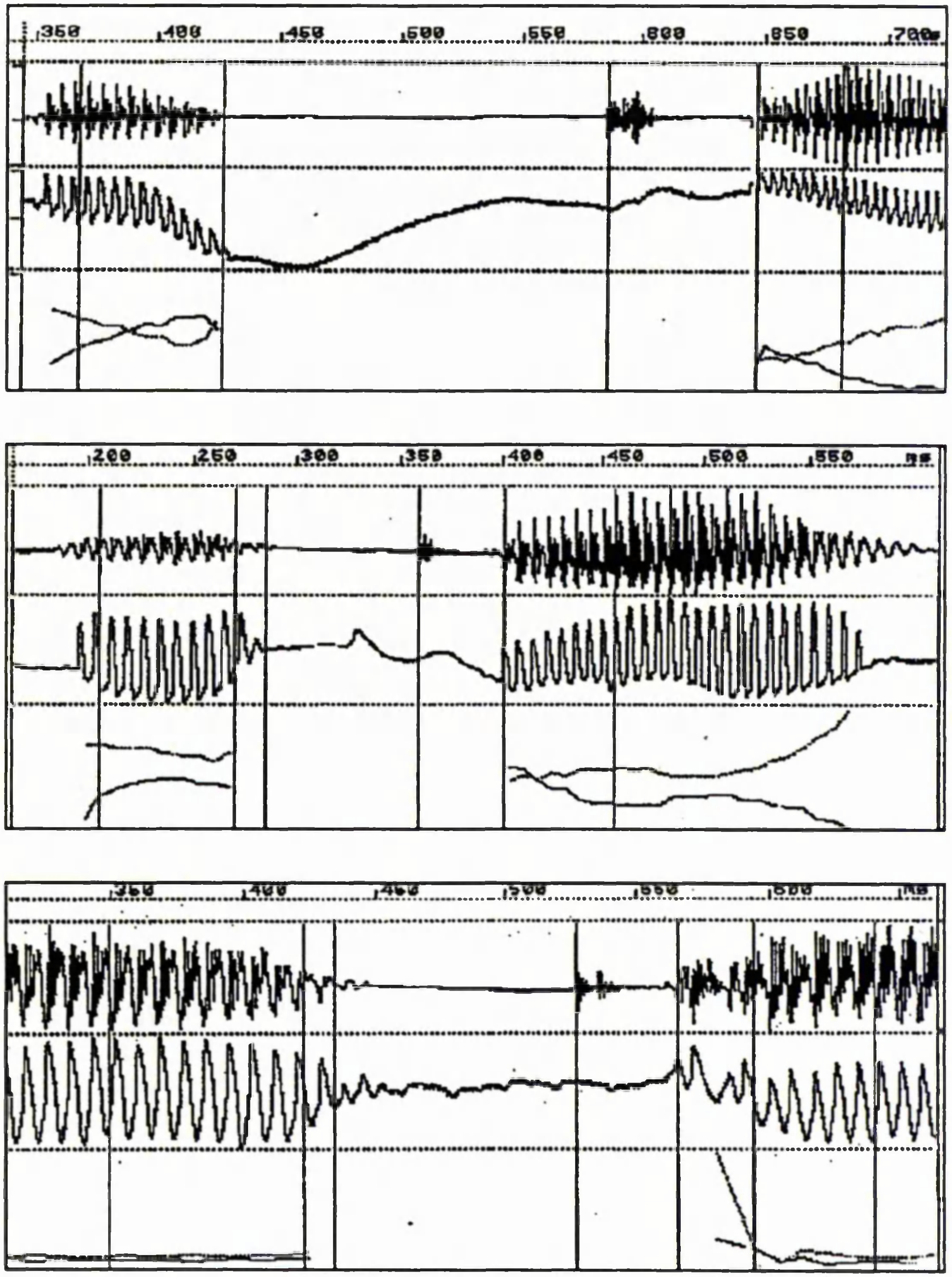



Figure 6.38(a-c): Illustrations of Sp waveform type 1, produced by (a) speaker F1, **hak'àa**, (b) speaker M13, **hak'àa** and (c) speaker M14, **shàak'aa**.

**Sp Waveform Type 2.**

The speech pressure waveform display of type 2 consonants between vowels appears as C1 followed by a gap or silent period with no noticeable noise, then a burst (B), followed by another silent period of random noise (the aspiration phase immediately following the burst) which continues into the following vowel. It is difficult in practice to separate the burst release from the following aspiration. The stops that best characterize this category are the geminate voiceless alveolar plosive /tt/ and voiceless velar plosives /k/ and /kk/, and the waveforms of these two stops are given in Fig. 6.39. The vowels following these stops begin with a high amplitude Sp (in contrast to type 1) which continues throughout the vowel.

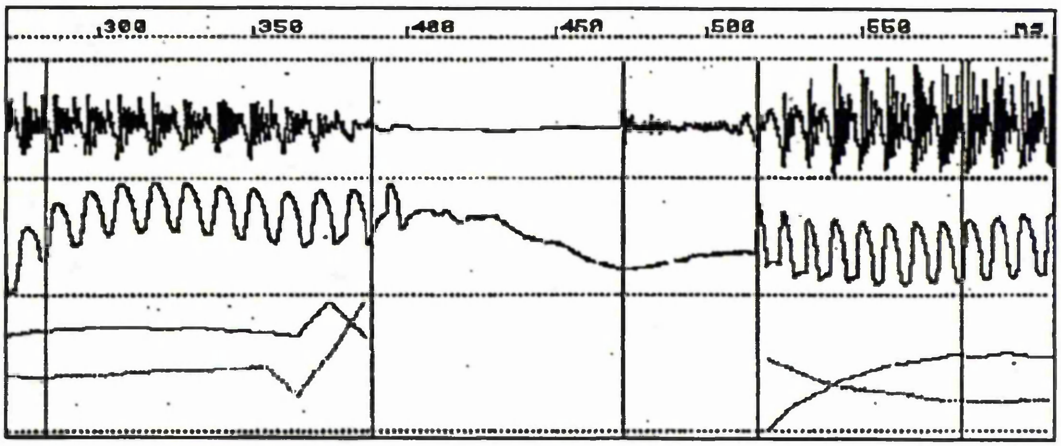



Figure 6.39(a): Illustrates the Sp waveforms of /k/ between two vowels /a/, produced by speaker M8, **kàakaa**

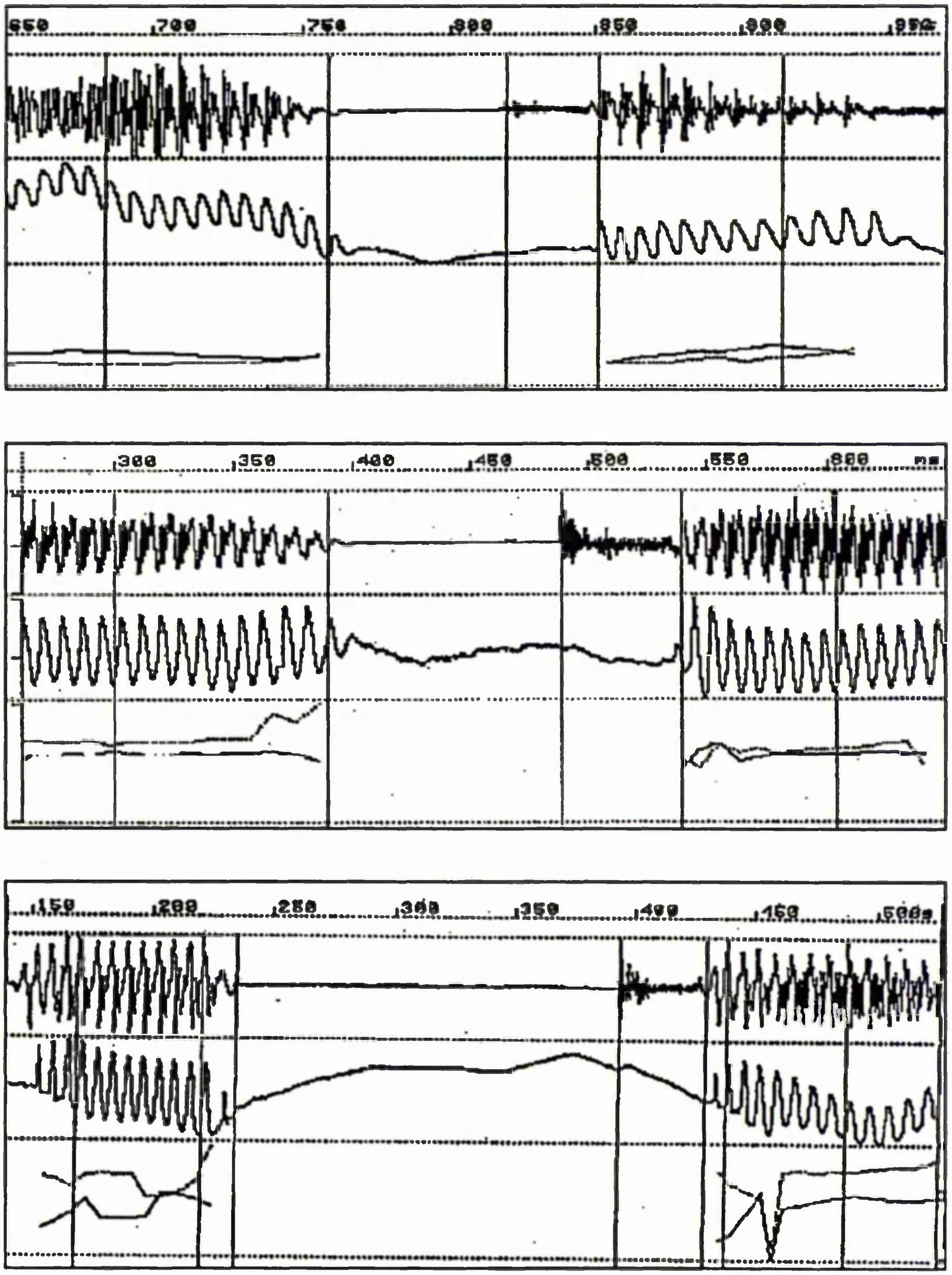



Figure 6.39(b-d): Illustrations of the Sp waveforms of /k/ and /tt/ between two vowels /a/, produced by (b) speaker M9, **dakàa**, (c) speaker M14, **kàakaa** and (d) speaker M15, **tattàaraa**.

**Sp Waveform Type 3.**

The speech pressure waveforms of this category between vowels appear as C1 followed by a silent period (without any random noise), then a burst (i.e. release of the consonant closure), followed in turn by a short period of random noise (which is the fricative release) and another silent period with no random noise (probably a glottal stop after the alveolar release), before the onset of the following vowel. This vowel starts with a high amplitude waveform which continues into the vowel. This waveform is typically associated with the ejective affricate /ts/ (cf. Fig. 6.40).

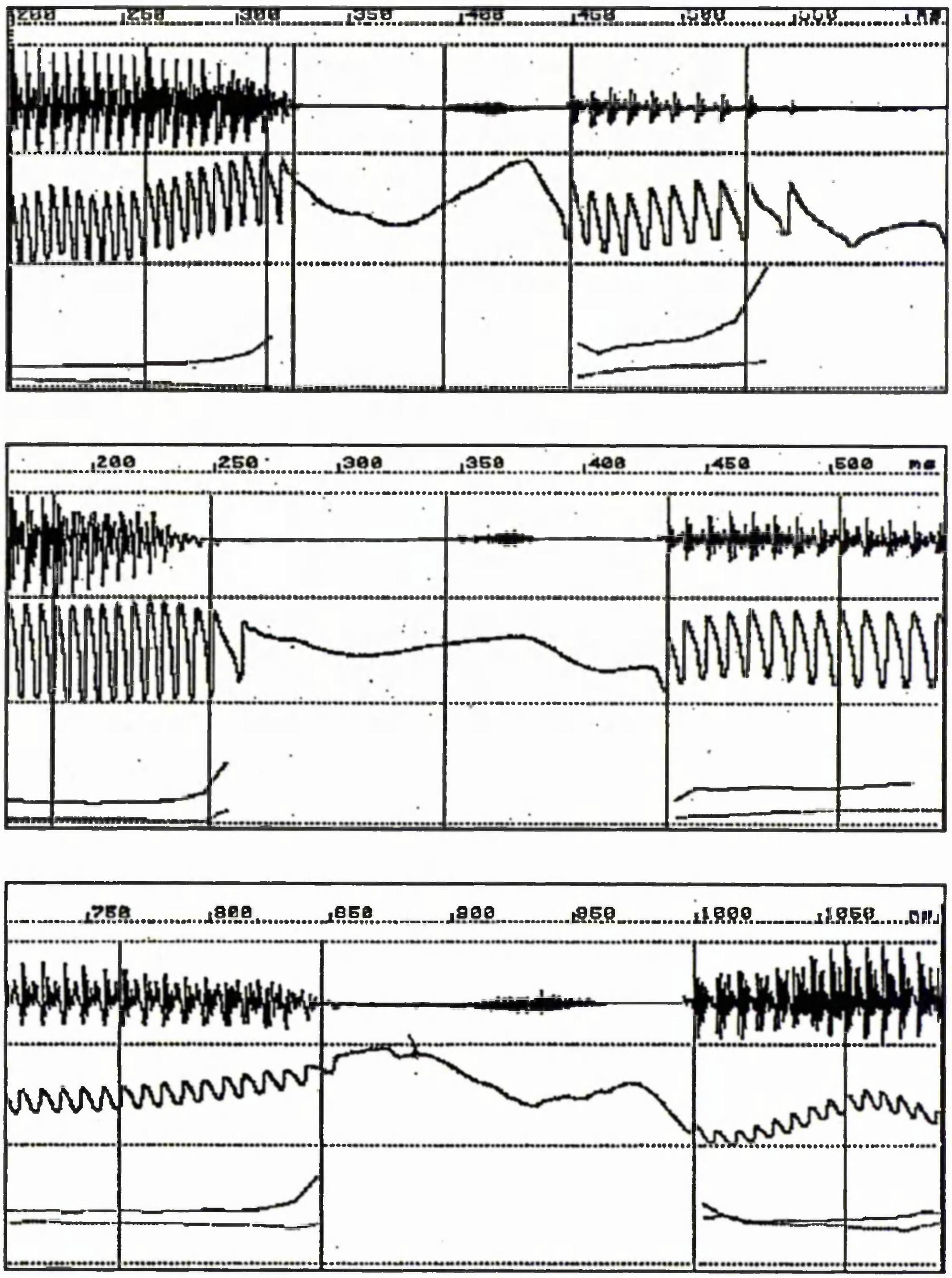



Figure 6.40(a-c): Illustrations of the Sp waveforms of the ejective affricate /ts/ between two vowels /a/ produced by (a) speaker M7, **tsaatsàa**, (b) speaker M7, **tsattsàaraa** and (c) speaker M9, **daatsàa**.

**Sp Waveform Type 4.**

The speech pressure waveforms of consonants of this type between vowels appear as C1 followed by a period of random noise throughout the duration of the consonant. The vowel following the consonant begins with a continuously changing speech pressure waveform pattern before stabilizing. The voiceless alveolar fricative /s/ is typically associated with this type of waveform (cf. Fig. 6.41).

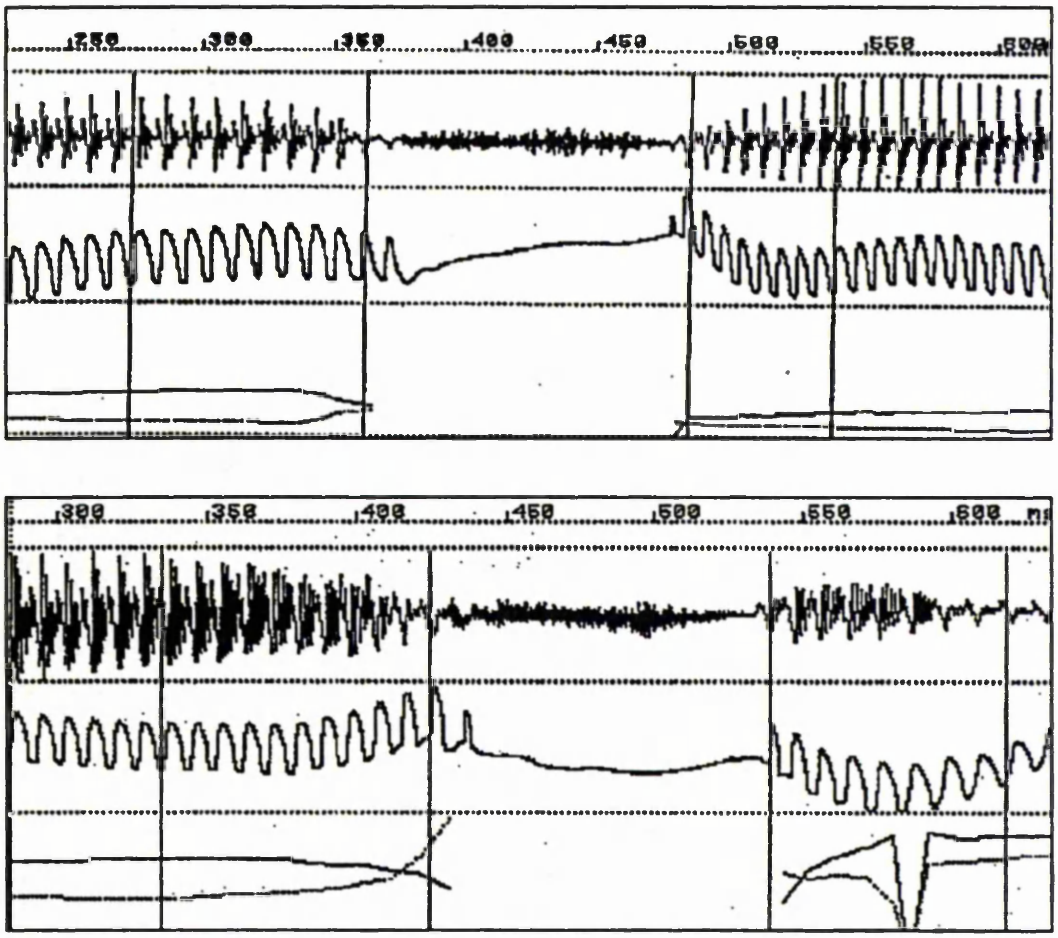



Figure 6.41(a-b): Illustrations of the intervocalic /s/, produced by (a) speaker M7, **làasaa** and (b) speaker M8, **taasàa**.

### 6.9.1 /k'/ and /k/.

#### 6.9.1.1 **Description of Lx and Sp waveforms.**

In Figs. 6.42 and 6.43 the waveforms of the glottalic and the non-glottalic velar stops are presented for comparison. A visual inspection of the two waveform types shows that they are different.

Fig. 6.42 shows examples of Sp and Lx waveforms for the glottalic stop /k'/ produced by speaker M10, **shàak'aa**, and F1, **hak'àa**; we can see that the consonant is voiceless throughout its duration. On the upper waveform after the release of the velar closure we find a strong burst of noise after which there is a period of silence of about 95 msec for M10 and 47 msec for F1 (probably representing a glottal stop) before the onset of voicing in the following vowel. There is a big upward vertical displacement of the Lx waveform during the closure period of the consonant segment particularly at the point where the consonant is released. While vertical displacement of the Lx waveform has not been shown to correlate directly with vertical movement of the larynx, this gross displacement is plausibly interpreted as resulting from the upward larynx movement for the ejective.

In Fig. 6.43 we find Sp and Lx waveforms for /k/ produced by speaker M9, **dakàa** and M14, **kàakaa.** Both waveforms show that the non-glottalic stop /k/ is also voiceless as there is no voicing during the closure period. After the release of the velar closure (B) there is a burst of random noise (aspiration) continuing into the following vowel. In contrast with /k'/ (cf. Fig. 6.42) the Lx waveform does not show appreciable vertical displacement.

Both /k'/ and /k/ can occur as geminates (cf. Fig. 6.44). I have been unable to pick up any consistent qualitative difference in the Lx waveforms between the geminates and the single stops. The major vertical displacement observed in the Lx waveform in the single glottalic /k'/ and its absence in plain counterpart can be observed in the geminates too. However, the speech pressure waveforms show that the single and geminate consonants in both glottalic and plain stops differ with regard to consonant duration and VOT duration (cf. section 6.14.4 for detailed discussion).

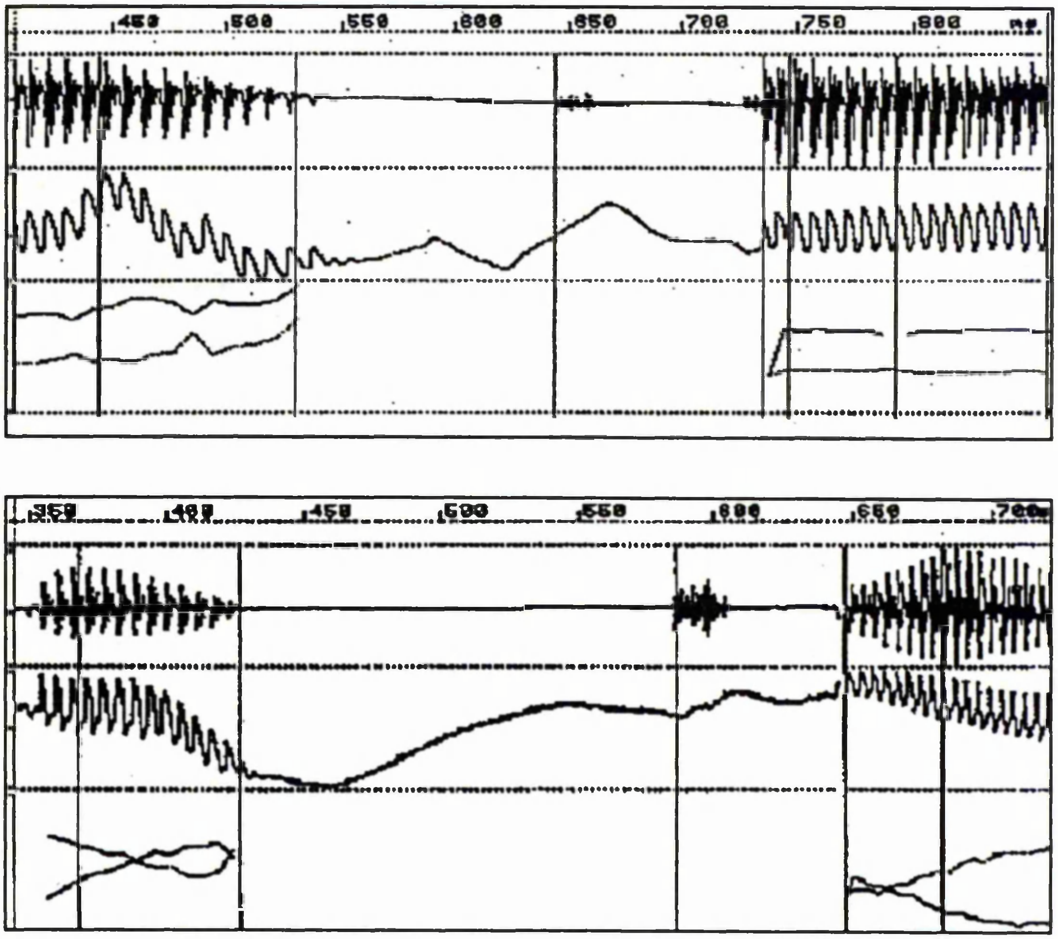



Fig. 6.42 shows Sp and Lx waveforms of /k'/ produced by speakers (a) M10, **shàak'aa** and (b) F1, **hak'àa**.

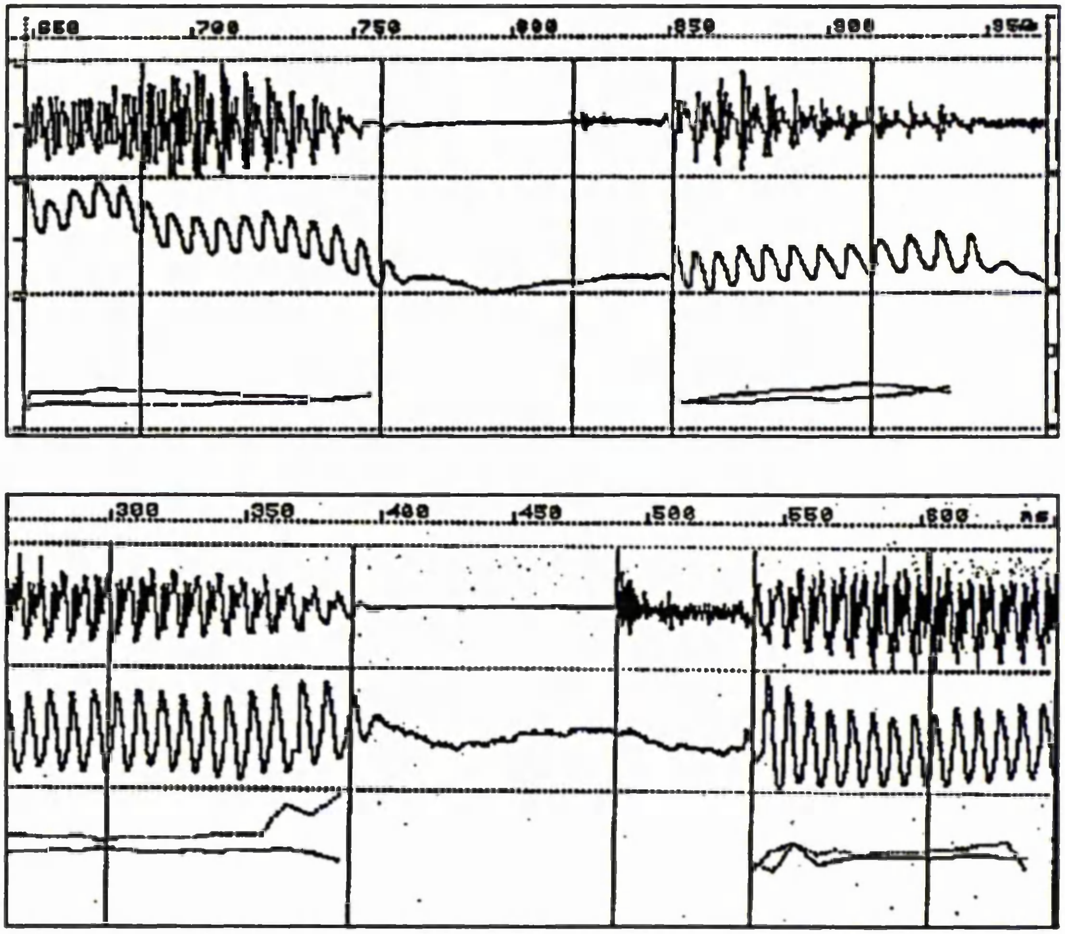



Fig. 6.43 shows examples of the single velar stop produced by speakers (a) M9, **dakàa** and (b) M14, **kàakaa**.

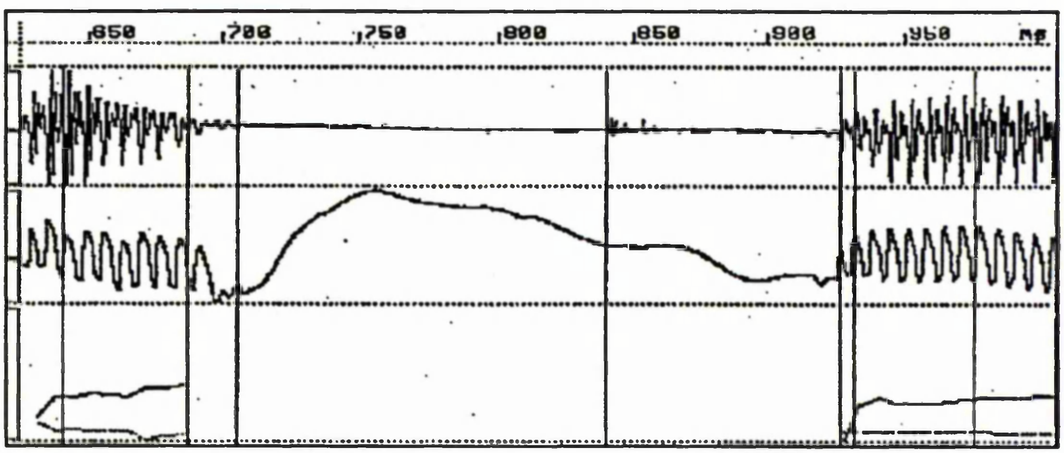



Figure 6.44(a): Examples of intervocalic /k'k'/ and /kk/ produced by speakers (a) M10, **sàk'ak'k'ee**.

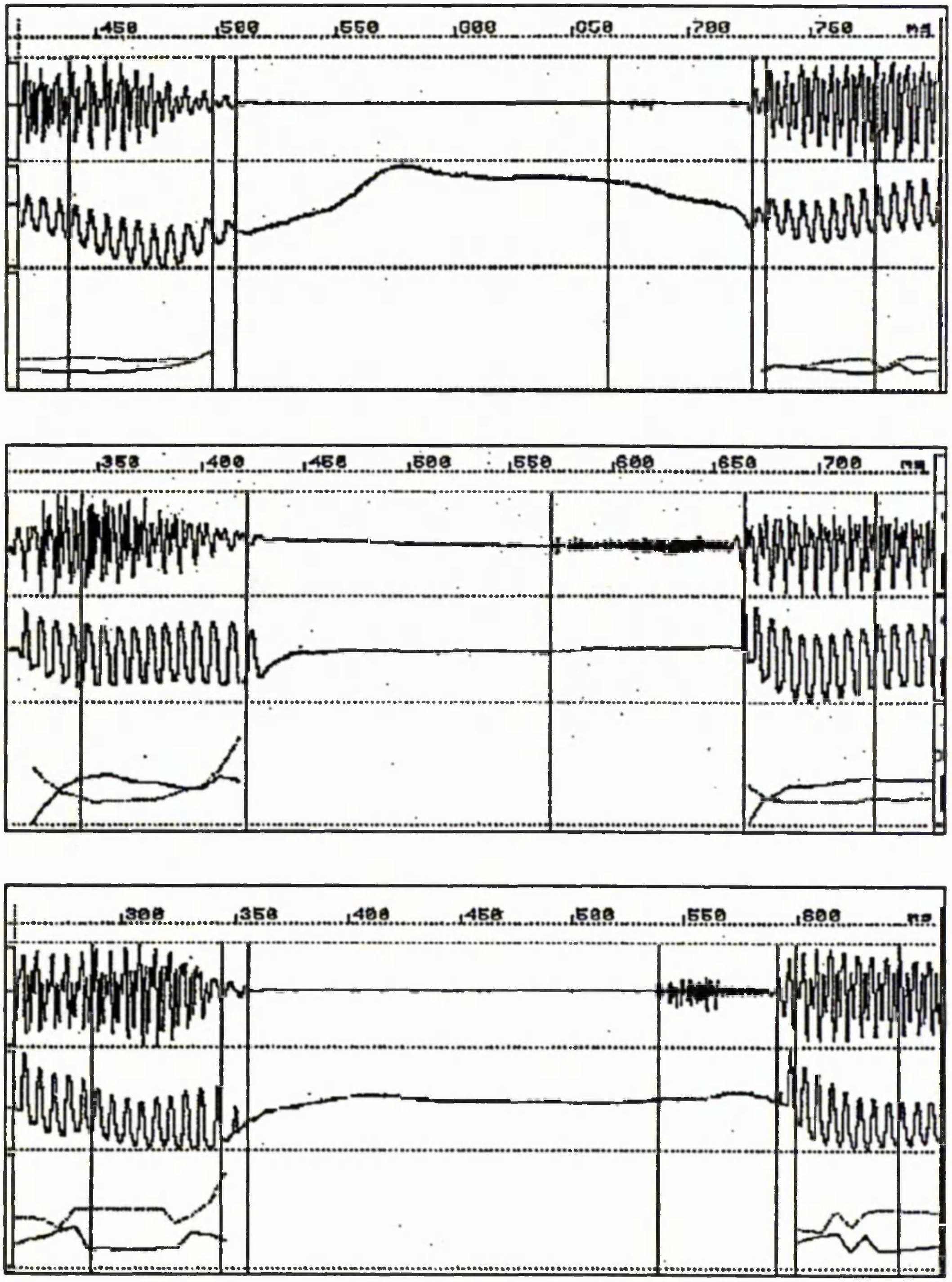



Figure 6.44(b-d): Examples of intervocalic /k'k'/ and /kk/ produced by speakers (b) M15, **sak'ak'k'ee**, (c) M8 and (d) M15, **cikakkee**.

With regard to the characteristic pattern of the waveforms for the glottalic stop /k'/ and plain /k/, most recordings of the two stops show the patterns described as Types 1 and 2. However, I found that there is some speaker variation in the glottalic stop /k'/. 13 speakers read 25 tokens in all. While 8 out of the 13 speakers consistently realized /k'/ as a proper ejective with the pattern just described, 2 speakers (M2 reading two tokens and M12 one token) realized it as [k] and the remaining 3 realized one token as [k] and the other as ejective [k'] (cf. Table 6.5). The speaker variation was in agreement with the findings of Lindau (1984). Lindau reported that 8 out of the 12 speakers she recorded realized the ejective /k'/ as true ejective, while the remaining 4 speakers realized it as [k] or as a voiced [g] (cf. Lindau 1984:153). It is not as yet clear whether this involves neutralization of the contrast between /k'/ and /k/, since I have undertaken no perceptual tests, although such a study would clearly be desirable and this awaits further research. All speakers realized /k/ as [k].

Table 6.5: Breakdown of variation according to speaker and between speakers for velar ejective /k'/.

| Speakers | Tokens read | Sp Waveform Patterns /k'/ | /k/ |
|---|---|---|---|
| M1 | - | - | - |
| M2 | 2 | - | 2 |
| M3 | 2 | 2 | - |
| M4 | 2 | 2 | - |
| M5 | - | - | - |
| M6 | 2 | 2 | - |
| M7 | - | - | - |
| M8 | 2 | 2 | - |
| M9 | 2 | 2 | - |
| M10 | 2 | 2 | - |
| M11 | 2 | 1 | 1 |
| M12 | 1 | - | 1 |
| M13 | 2 | 1 | 1 |
| M14 | 2 | 1 | 1 |
| M15 | 2 | 2 | - |
| F1 | 2 | 2 | - |
| Total | 25 | 19 | 6 |

6.9.2 /ts/ and /s/.

### 6.9.2.1 **Description of Lx and Sp Waveforms.**

The glottalic affricate /ts/ has been described by Ladefoged (1968:5) not as an ejective affricate but as an ejective fricative [s'], although he gives [t'] as the Katsina dialect variant. Accordingly, he investigated the articulatory movements in the production of this segment, and reports that it consists of

> "an interval of about 40 msec between the end of the recorded fricative sound and the release of the glottal stop, and a further short interval before the vocal folds start vibrating regularly" (Ladefoged 1968:5-6).

See Fig. 6.12 showing a spectrogram of the Hausa phrase **tsuntsàyee nèe**"they are birds" taken from Ladefoged (1968). Similarly Meyers (1976) describes /ts/ as an ejective fricative and gives two possible articulatory patterns for the segment:

1 in which the pattern of articulatory timing shows a glottal occlusion which is released with laryngealized voicing during the friction of the /s/, and
2 representing an articulatory pattern where during the friction noise of the /s/ there is no longer a glottal component (cf. Fig. 6.10). In my data a silent period not only follows the friction but also precedes it, which I consider an indication of a genuine affricate. In Fig. 6.45 the Sp and Lx waveforms of the glottalic affricate /ts/, /tts/, the plain voiceless fricative /s/, /ss/ and the plain voiceless alveolar stop /tt/ are given for comparison.

The figure clearly shows at consonant onset for /ts/ and /tts/ the Lx waveform which I associate with glottal closure, indicating that glottal stricture lasts the full duration of the consonant and does not merely begin at some point during the oral constriction. The OQ decreases rather than increases before the consonant, anticipating adduction rather than abduction of the vocal folds (cf. Fig. 6.45(a) for **tsaatsàa** by M7). Similarly on the Lx waveform there is an upward vertical displacement (which is variable) during the closure period of the segment. In Fig. 6.45 (a & c) it is more prominent at the fricative portion of the segment. In Fig. 6.45 (b) it is more prominent during the /t/ portion of the segment. While vertical displacement of the Lx waveform has not been shown to correlate directly with vertical movement of the larynx, this gross displacement is plausibly interpreted as resulting from the upward larynx movement for the ejective affricate. This is in contrast to the voiceless fricative /s/ (cf. Fig. 6.45).

We can see that /s/ is voiceless and has friction (random noise) throughout the duration of the consonant and the OQ increases rather than decreases before the consonant, anticipating abduction rather than adduction of the vocal folds. Fig. 6.45 also shows the waveforms of the non-glottalic stop /tt/. It can be seen that the consonant begins with a silent period lasting about three quarters of its total length (C1, to the burst (B)). After the release of the segment there follows a period of aspiration averaging 25.4 msec, characterized by some random noise before the articulation of the following vowel begins.

Both the glottalic and the non-glottalic consonants can occur as geminates. Fig. 6.45 (c, e and f) shows the waveforms of the geminates. I have not been able to observe any consistent qualitative difference in the Lx waveforms between the geminates and the corresponding single consonants. The major vertical displacement of the Lx waveform at the fricative portion of the segment observed in the single glottalic affricate /ts/ and its gradual rise in the voiceless stop and fricative counterparts can be observed in the geminate too. However, the speech pressure waveforms show that the single and the geminate segments in both glottalic affricate, plain stop and fricative differ with regard to duration (cf. section 6.14.3 below for discussion).

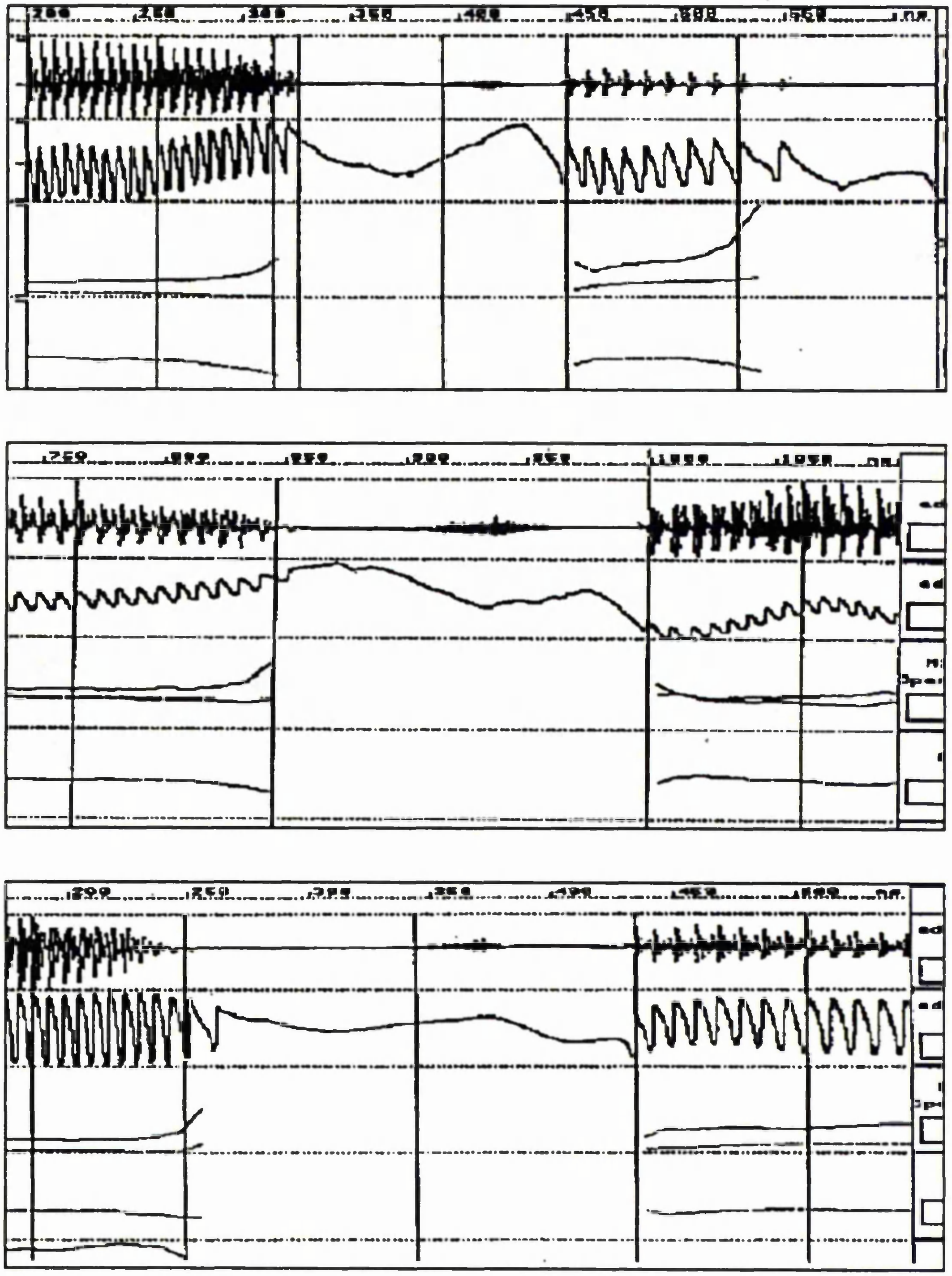


Figure 6.45(a-c): Examples of waveforms for /ts/ and /tts/: (a) M7, **tsaatsàa**, (b) M9, **daatsàa**, (c) M7, **tsattsàaraa**.

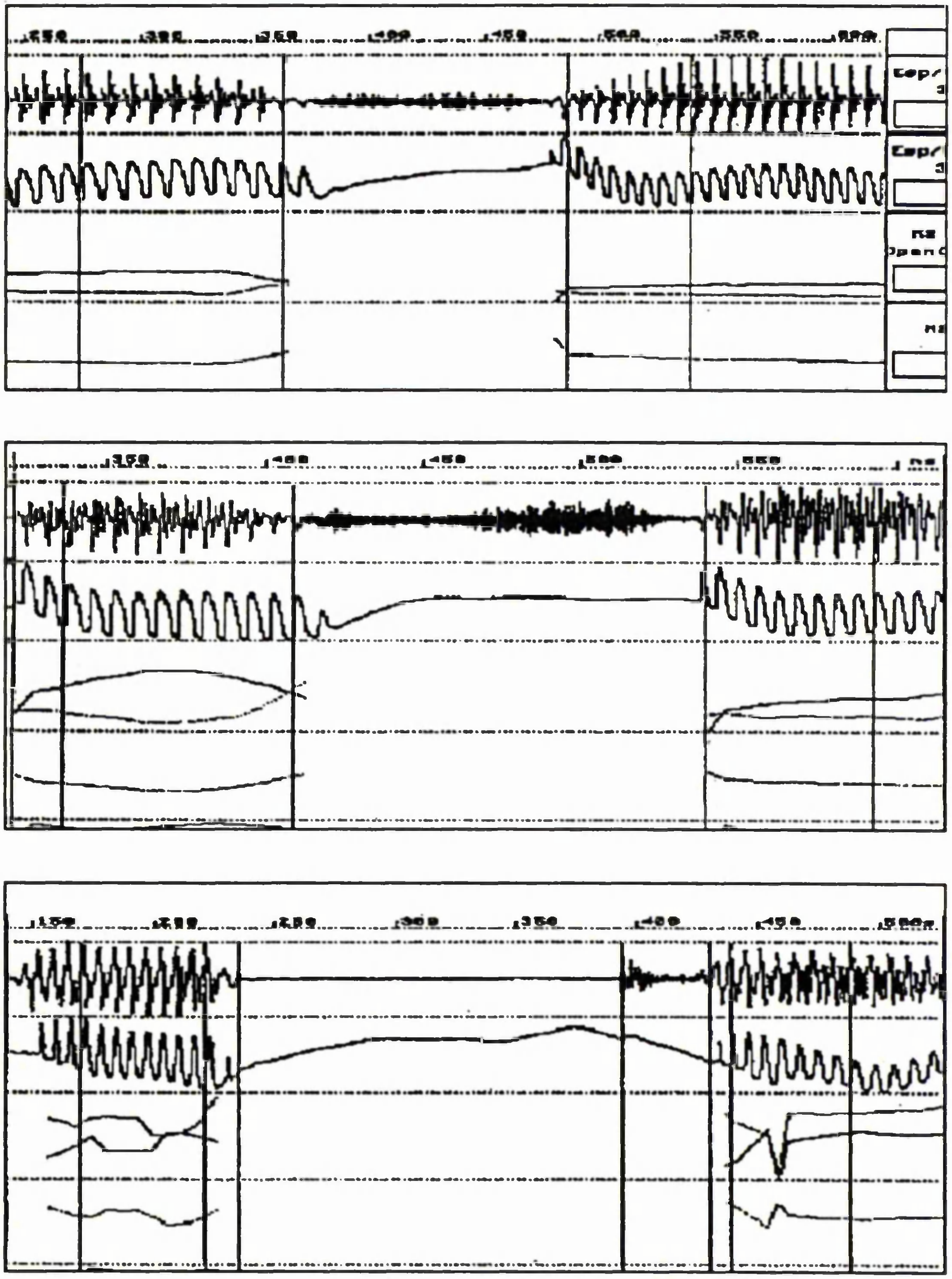


Figure 6.45(d-f): Examples of waveforms for /s/, /ss/ and /tt/: (d) M7, **làasaa**, (e) M7, **masassabii**, (f) M15, **tattàaraa**.

Comparing the glottalic and the non-glottalic consonants, I found that the glottalic affricate /ts/ starts with a long period of silence for the /t/ closure followed by random noise at the release of the segment and then another period of silence (probably a glottal stop) before the articulation of the following vowel begins. Kraft and Kraft (1973) have talked of /ts/ as a "combination of /t/ plus /s/ with simultaneous glottal closure" (1973:25). In comparison, the non-glottalic consonant /s/ has random noise throughout. The stop geminate /tt/ is also voiceless throughout and is aspirated immediately before the onset of voicing in the following vowel.

It is evident from the waveforms obtained that considerable speaker to speaker variation occurs in the articulation of /ts/. 14 speakers were recorded, most reading two tokens. The data shows that 10 produced a proper ejective affricate /ts/ for both tokens (M9, M11 and F1 read one token each), and 2 of the others each produced one proper ejective affricate and one voiceless alveolar fricative. The remaining 2 speakers (M12 and M14 reading 1 and 2 tokens respectively) produced a voiceless alveolar fricative /s/ all of the time (cf. Table 6.6). For the geminate nine out of ten speakers produced a proper ejective affricate while one (M14) produced a voiceless alveolar fricative /s/. It is not as yet clear whether this involves neutralization of the contrast between /ts/ and /s/, since I have undertaken no perceptual tests, although such a study would clearly be desirable. All speakers produced /s/ and /tt/ without variation.

Table 6.6: Breakdown of variation according to speaker and between speakers for alveolar ejective /ts/.

| Speakers | Tokens read | Sp Waveform Patterns /ts/ | /s/ |
|---|---|---|---|
| M1 | - | - | - |
| M2 | 2 | 2 | - |
| M3 | 2 | 2 | - |
| M4 | 2 | 2 | - |
| M5 | - | - | - |
| M6 | 2 | 1 | 1 |
| M7 | 2 | 2 | - |
| M8 | 2 | 2 | - |
| M9 | 1 | 1 | - |
| M10 | 2 | 2 | - |
| M11 | 1 | 1 | - |
| M12 | 1 | - | 1 |
| M13 | 2 | 2 | - |
| M14 | 2 | - | 2 |
| M15 | 2 | 1 | 1 |
| F1 | 1 | 1 | - |
| Total | 24 | 19 | 5 |

## 6.10 Quantitative Analysis: Open Quotient (OQ) and Fundamental Frequency (Fo).

### 6.10.1 Introduction.

In this section, we shall be concerned with the following:

1. Normalized laryngographically-derived open quotient (cf. section 5.9.1 and below on normalized procedure). We should wish to see this as a measure of phonation type, higher OQ values indicating relatively breathy phonation and lower values indicating relatively constricted glottis and laryngealization.
2. Fo movement and its relationship to OQ.
3. Closure duration.

First, however, it is necessary to consider some general questions concerning the data base, namely, balance between speakers and elimination of outliers.

### 6.10.2 Balance Between Speakers Within the Data Base.

It is desirable that speakers should be as evenly represented in the data base as possible. A closer look at the data shows that, even after standardization, there is a great deal of inter-speaker variation with regard to the degree of difference in OQ and Fo from one type of consonant to another.

Upon examination of Table 6.7 which gives the mean OQpre values (cf. section 6.6.7 for an explanation of this notation), we see that the representation of speakers is uneven as the N values in the table show. Two speakers, M1 and M5 are very under-represented (for M1, there are only four tokens, and for M5, ejective and plain voiceless tokens are lacking). In the statistical analysis the data from these two speakers have been left out. As regards the rest of the speakers we have at least one token for each type of single consonant with the exception of glottal stop (not recorded for M1, M5, M6, M11 and M15).

The next most serious discrepancies (after leaving out M1 and M5) are the geminate consonants. Not all speakers recorded the geminates. In the analysis, two steps were taken:

1 single consonants were first compared with each other; and then
2 the single consonants were compared with the geminates for those speakers who recorded both single consonants and geminates.

### 6.10.3 Elimination of Outliers.

I have also been conservative with regard to elimination of cases that have been found to be very different from the rest of the data. The Lx waveform was used as a yard stick during the elimination exercise,and cases were eliminated from consideration only if there was clear reason to think that something had gone wrong in determining OQ or Fo values.

In elimination exercises, I considered cases in which the important characteristics of the Lx waveform may have been too subtle for the present algorithm to identify. This might be due to the fact that the laryngograph gives very little information about the activity of the vocal folds when there is no proper contact between them, so that it is possible for the folds to make considerable closing gestures (generating substantial acoustic energy), or to be held quite close together (minimizing the damping effects due to the coupling-in of the subglottal cavities), without considerable changes to the course of the Lx waveform. Fourcin (1981) has argued that Lx waveform gives little information if any about vocal fold activity when the folds are not in contact, that it cannot objectively be taken as a measure of the glottis **per se** (cf. Howard and Lindsey 1987 and Lindsey et al. forthcoming).

Take for example Fig. 6.46 (a) produced by speaker M10, **tàb'ab'b'ee** token 288, and (b) produced by speaker M11, **'yaa'yaa**, token 231 in which low amplitude secondary closures alternate with high amplitude closure of the shape corresponding to low OQ. The OQ plot, however, shows that some of the small cycles have been missed by the algorithm. The consequence is that the period of the secondary closure is included in the measured OQ phase of the preceding primary closure, giving a misleading high OQ value. In all, eight tokens all containing /ʔ̲/, /'y/ or glottalic stops were eliminated from the study on the basis that the algorithm detected a long open phase although a small vertical deflection indicating a secondary glottal closure was visible in the Lx waveform display. The tokens are **fad'àa** token 10 and **fàd'aa** token 11, produced by speaker M9, **saab'àa** token 25, produced by speaker M14, **saab'àa** token 91, and **tsaatsàa** token 94, produced by speaker M13, **tsòotsoo** token 145, produced by speaker M15, **tàʔ̲adii** token 169, produced by speaker M12 and **tàb'ab'b'ee** token 288, produced by speaker M10. Consider now Fig 6.47 produced by speaker M3, **saab'àa**, token 243, or **tàb'ab'b'ee**, produced by speaker M14, token 44 which differ in that there is no visible deflection at all corresponding to the inferred secondary closing gesture. Tokens of this type, in which a secondary closure or closing gesture was strongly suspected (on the basis of the surrounding cycles and/or auditory analysis), but where the Lx waveform display exhibited no deflection in the waveform and the algorithm detected a correspondingly high OQ, were nonetheless included in the data base for statistical analysis.

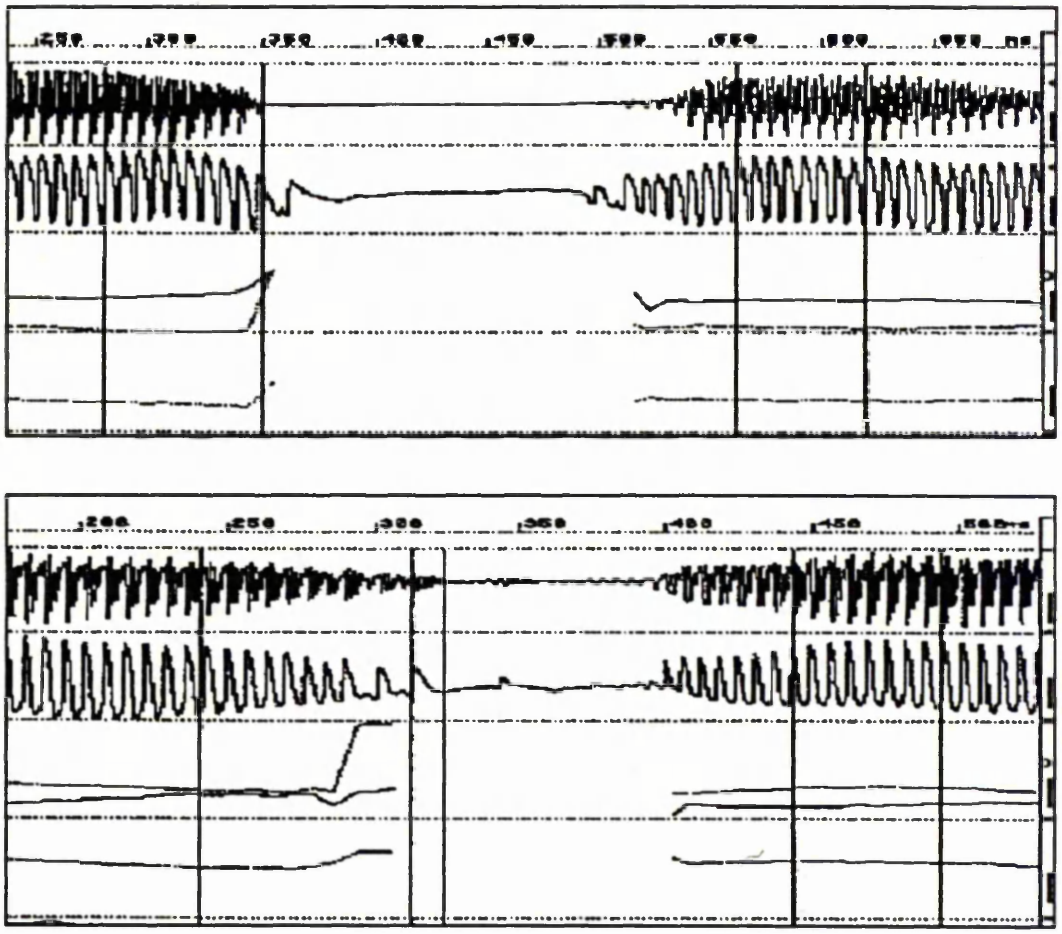


Figure 6.46(a-b): Illustrative cases which are eliminated: (a) is of intervocalic /b'b'/ in the word **tàb'ab'b'ee** produced by speaker M10, and (b) /'y/ in the word **'yaa'yaa** produced by speaker M11.

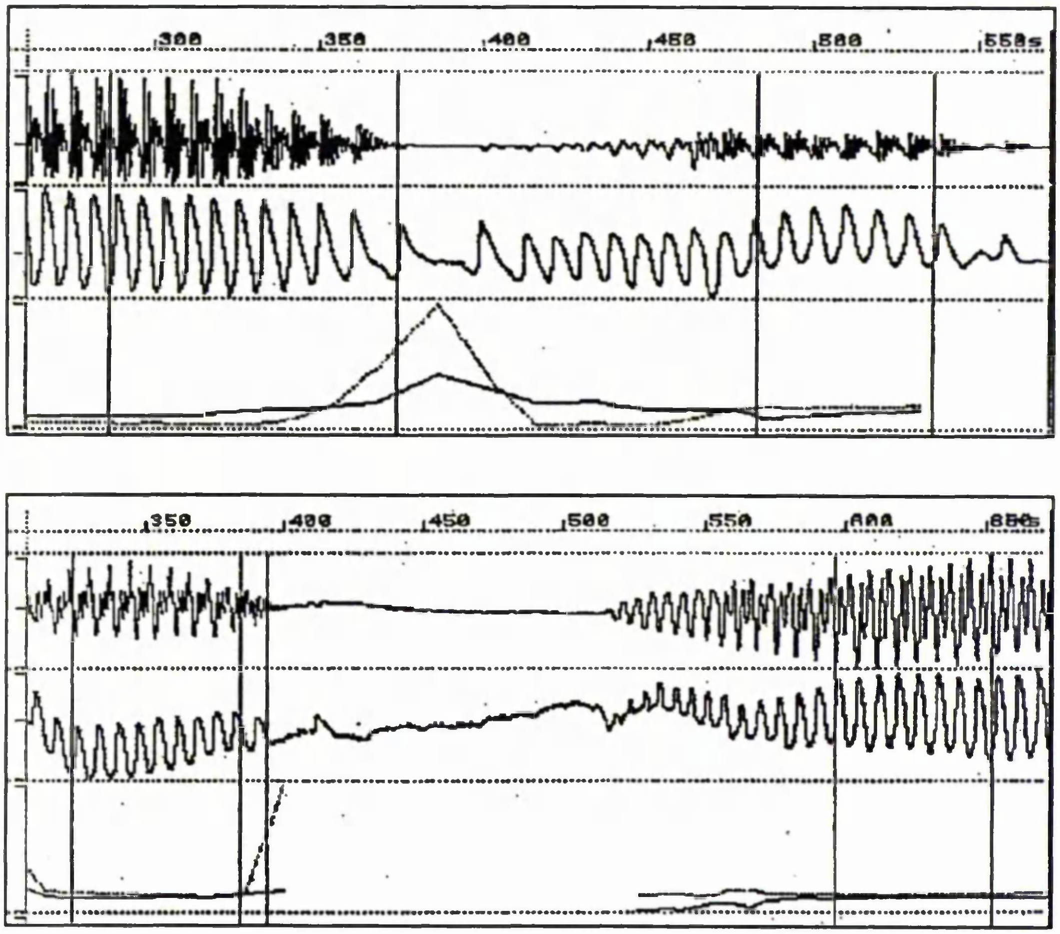



Figure 6.47(a-b): Illustrative cases of Lx waveforms suspected but included in the analysis: (a) intervocalic /b'/ in the word **saab'àa**, produced by speaker M3 and (b) /b'b'/ in the word **tàb'ab'b'ee**, produced by speaker M14.

### 6.10.4 Statistical Procedures.

A one-way analysis of variance (ANOVA) was used in comparing consonant types. The technique provides a test of the hypothesis that there is no difference between the various groups with regard to the dependent variable under consideration, in other words that all groups are drawn from the same population. The method provides no information concerning the location of differences, that is which groups were different from which. There are two general approaches in making comparisons between groups:

1 **Planned Comparisons.** This involves a limited number of comparisons (based on the **t** statistic) between groups or combinations of groups; in this case, all the comparisons must be independent.

2 **Multiple Comparisons.** This involves comparisons between all pairs of groups.

When the dependent variables relating to OQ and Fo are considered, the groups defined by consonant type differ both with regard to size and with regard to magnitude of variance. For this reason, I have used separate variance estimates in computing **t** values for planned comparisons and a conservative procedure (the Scheffé test) in multiple comparisons.

The statistics were computed using SPSS programs on an IBM personal computer. See Nie et al. (1975) and Norusis (1986).

6.10.5 Open Quotient.

For OQ, the aim is to compare the observed values with modal values for each speaker. As we do not have enough data concerning modal OQ, one possibility would be to use mean OQpre and OQpost values to estimate modal OQ for each speaker. However, there are problems with such a procedure, as it has been found that both OQpre and OQpost may be influenced by preceding or following consonants, particularly if the vowel in question is short. Because of this possible distortion due to a preceding or following consonant, we have adopted a different procedure. Each speaker's modal OQ was estimated in the following way: the average of the four OQ measures in the word **yàayàa** 'how' (which consists entirely of sonorant segments and, it was assumed, would exhibit "modal" voice) was calculated for each speaker. This estimate of modal OQ, we call "average open quotient" (hereafter AVOQ). Thus, for speaker (X),

**AVOQ (X) = ¼(OQpre+OQ1+OQ2+OQpost) yàayàa(X).**

AVOQ, mean OQ at pre, and standard deviation for OQ at pre for the word **yàayàa** for all speakers (except F1) are given in Table 6.7.

Modal averages calculated, not from this one word (**yàayàa**) but rather from values of all data at positions pre and post, would obviously be based on a much larger number of observations, but as already mentioned above, both pre and post may be affected by surrounding consonants where the vowel is short. Nonetheless, averages based on all observations have been calculated; these are displayed with one standard deviation above and below in Fig. 6.48. For most speakers, these averages agree well with the averages on **yàayàa**, giving us confidence in the validity of the procedure.

It is also clearly visible from Fig. 6.48 and Table 6.7 that low modal OQ values seems to be confined to East (Kano) speakers (M1-M10). It is not as yet clear whether this distinguishes the two dialect areas; this matter needs further investigation.

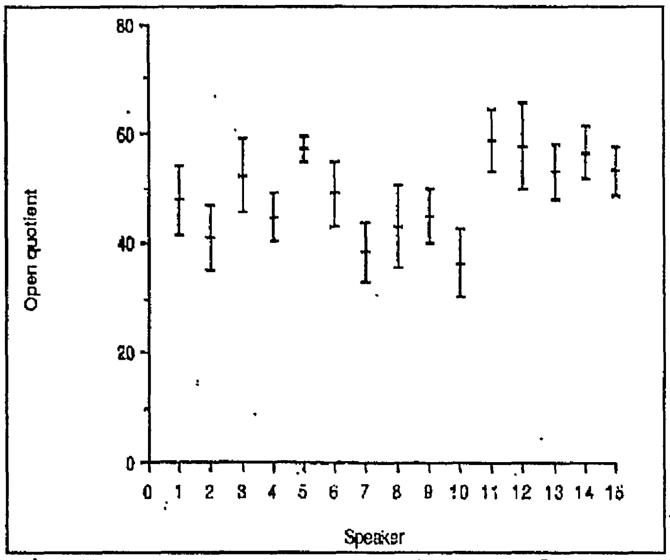


Figure 6.48: Mean OQ at pre plus and minus 1 standard deviation.

Table 6.7: AVOQ, mean OQ at pre, and standard deviation for OQ at pre for all speakers pronouncing the word yàayàa.

| | OQ at pre | | | |
|---|---|---|---|---|
| Speaker | AVOQ | Mean | s.d | N |
| M1 | 57.75 | 48.00 | 6.22 | 4 |
| M2 | 40.00 | 41.28 | 5.85 | 29 |
| M3 | 59.50 | 52.45 | 6.54 | 29 |
| M4 | 44.50 | 44.82 | 4.33 | 28 |
| M5 | 59.50 | 57.33 | 2.29 | 9 |
| M6 | 50.75 | 49.19 | 5.85 | 21 |
| M7 | 38.50 | 38.50 | 5.41 | 27 |
| M8 | 44.50 | 43.24 | 7.47 | 29 |
| M9 | 49.75 | 45.11 | 4.91 | 19 |
| M10 | 35.00 | 36.55 | 6.12 | 29 |
| M11 | 65.00 | 58.74 | 5.67 | 19 |
| M12 | 54.75 | 57.78 | 7.84 | 27 |
| M13 | 54.25 | 53.00 | 4.95 | 20 |
| M14 | 56.50 | 56.66 | 4.86 | 29 |
| M15 | 60.00 | 53.33 | 4.43 | 27 |

As already observed above, for each token we have four values: OQpre, OQ1, OQ2 and OQpost. These OQ values for all data were divided by average modal OQ value for the speaker in question, then multiplied by 100 to give a normalized open quotient (NQ). Thus, for token (Y) produced by speaker (X):

**NQpre (Y) = 100 (OQpre (Y) / AVOQ (X))**
**NQ1 (Y) = 100 (OQ1 (Y) / AVOQ (X))**
**NQ2 (Y) = 100 (OQ2 (Y) / AVOQ (X))**
**NQpost (Y) = 100 (OQpost (Y) / AVOQ (X))**

Thus, NQ values represent OQ values as a percentage of speaker estimated modal OQ (100).

6.10.6 Fundamental Frequency.

As regards Fo, the state of affairs is more complicated. Individual speaker characteristics and the variety of the tonal patterns in the data make the absolute Fo values (or their means) in the environments of different consonant types rather unrevealing. To make matters easier, I decided to consider the degree of fall or rise in Fo from the preceding vowel to the beginning of the consonant (C1) and from the end of the consonant (C2) to the following vowel. An obvious way of doing this would be to compare Fo1 with Fopre and Fo2 with Fopost. However, this procedure was found to be unsuitable because of the possible distortion due to the effects of surrounding consonants and, in the case of post, of word-final drop in Fo. I therefore chose to adopt a different procedure, comparing Fo1 with MFo1 (maximum Fo between pre and C1) and Fo2 with MFo2 (maximum Fo between C2 and post). This gives two new variables. For token (Y):

1 **FRAT1 (Y) = 100(Fo1 (Y) / MFo1 (Y)) and**
2 **FRAT2 (Y) = 100(Fo2 (Y) / MFo2 (Y)).**

FRAT1 and FRAT2 (FRAT means Frequency Ratio) represent Fo1 and Fo2 values as a percentage of maximum Fo during the preceding and following vowels respectively.

## 6.11 Single Consonants.

### 6.11.1 NQ at C1.

Consider Figs. 6.49-6.51 which show the mean NQ values for each speaker at the intervocalic consonantal positions, pre, C1, C2 and post, for /'y/, /b'/ and /d'/, and for /k/ and /s/. Figs. 6.49 and 6.50 clearly show that NQ decreases for /'y/ and /b'/ and /d'/ and Fig. 6.51 shows that it increases for plain voiceless /k/ and /s/. For most speakers, the greatest effect (decrease) is at C1 (the consonant onset) rather than at C2 (consonant offset) for /'y/, /b'/ and /d'/. Fig. 6.50 shows a decreasing NQ pattern at C1 for /b'/ and /d'/ similar to /'y/ (Fig. 6.49) although the effect is slightly weaker. Further, there is a great deal of inter-speaker variation.

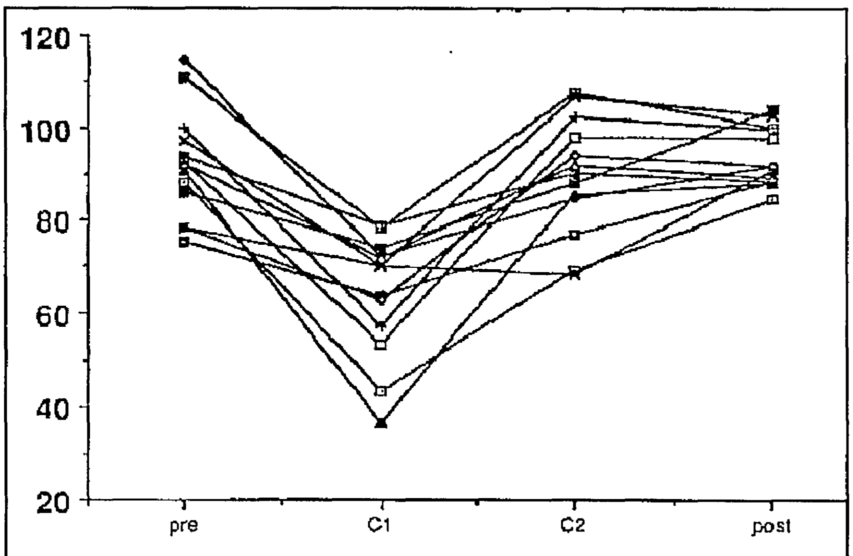



Figure 6.49: Mean NQ for each speaker at the intervocalic consonantal positions pre, C1, C2 and post for /'y/.

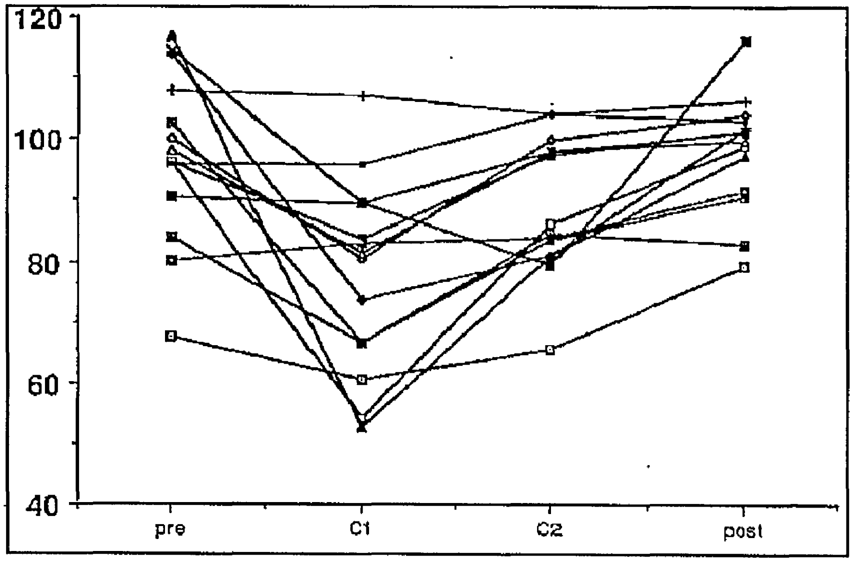



Figure 6.50: Mean NQ for each speaker at the inter-vocalic consonantal positions pre, C1, C2 and post for /b'/ and /d'/.

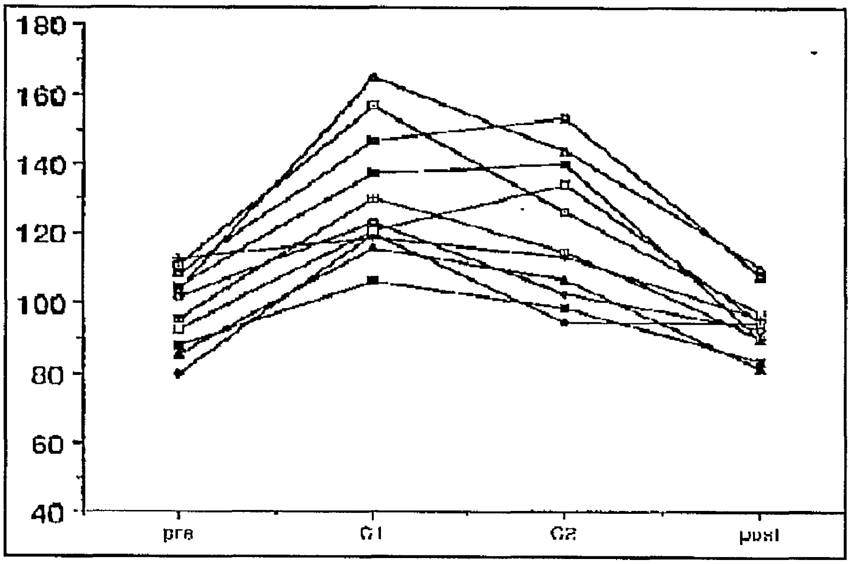
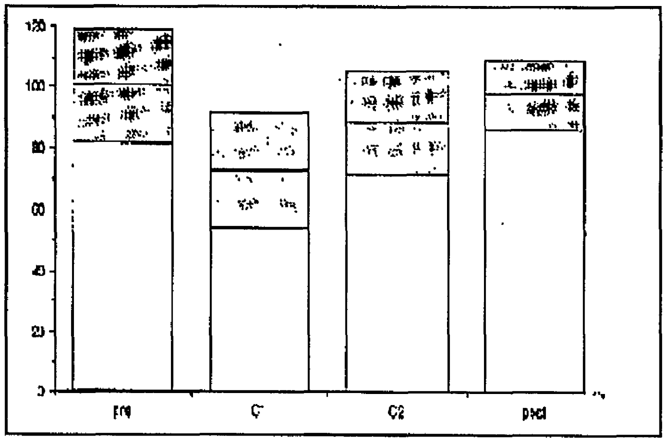



Figure 6.51: Mean NQ for each speaker at the inter-vocalic consonantal positions pre, C1, C2 and post for /k/ and /s/.

Figs. 6.52-6.54 show the NQ values averaged across speakers at the different consonantal environments for all the glottalic consonants, single and geminate (Fig. 6.52) all plain voiced consonants, single and geminate (Fig. 6.53) and all plain voiceless consonants including single and geminate (Fig. 6.54). Each of the figures also shows one standard deviation above and below the mean. It is evident that mean NQ decreases in the environment of the glottalic consonants, stays fairly constant at around the modal (100) value for the plain voiced consonants and increases for the plain voiceless consonants.

Figure 6.52(a-b): Mean NQ

(a) across speakers for all glottalic consonants and



(b) for glottalic /b'/ and /d'/.

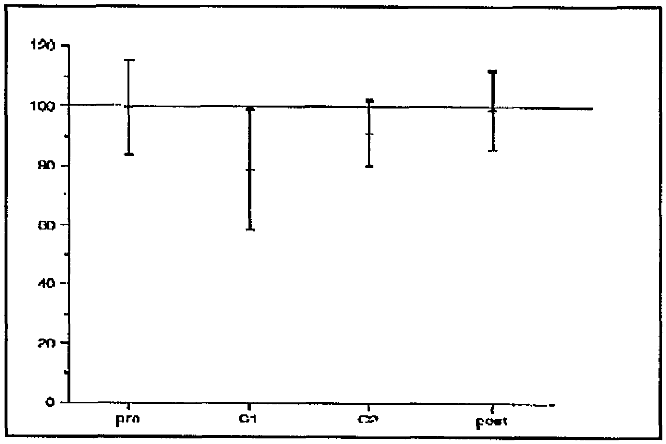



Figure 6.53: Mean NQ values across speakers for all plain voiced consonant plus geminates.

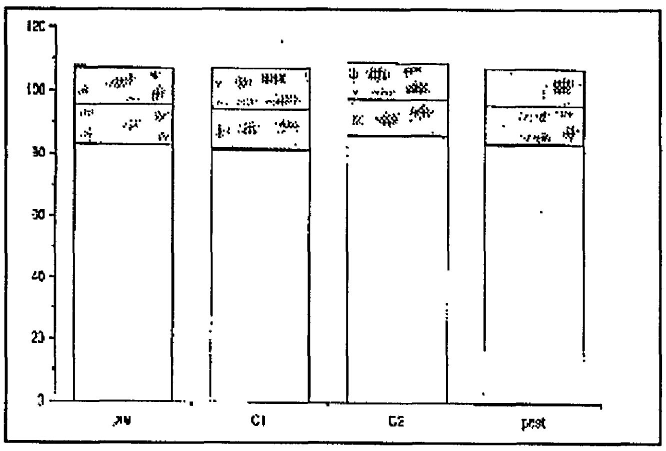
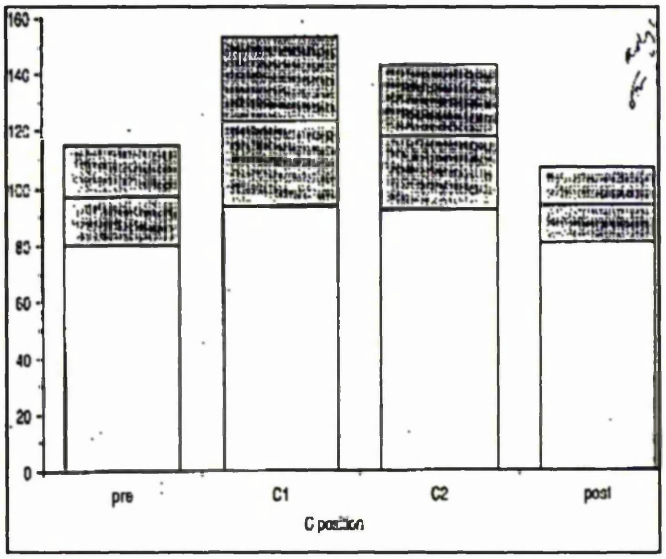


Figure 6.54 Mean NQ values across speakers for all plain voiceless consonants plus geminate.

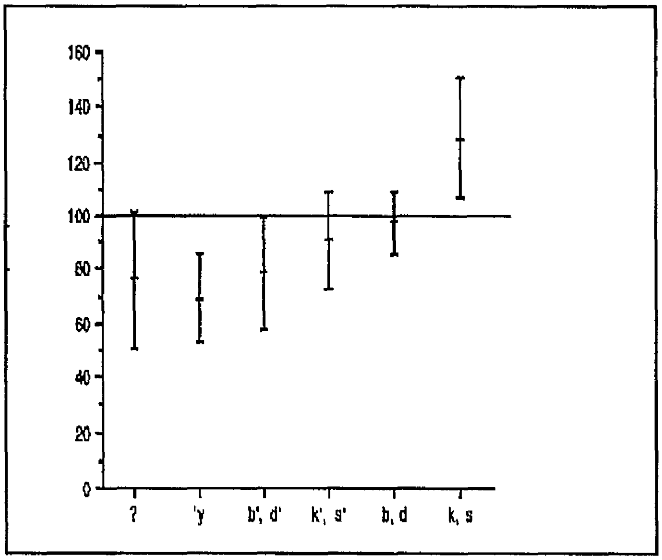



Upon examination of the averages of the data, it is clear that position C1, the consonant onset, is the point at which the three groups are most differentiated. This may be quantified by carrying out one-way ANOVA for the NQ at C1 and NQ at C2 by consonant type (with 6 type categories as in Table 6.8). The resultant variance ratio (F) was found to be higher for NQ at C1 (F = 47.98) than at C2 (F = 17.66). Table 6.8 and Fig. 6.55 show the NQ means and the standard deviations at position C1 for the various consonant types.

Table 6.8: Means and standard deviations for NQ1 for the various consonant types.

| | Consonant Type | N | Mean | s.d |
|---|---|---|---|---|
| 1 | /?/ | 19 | 76.23 | 25.38 |
| 2 | /'y/ | 13 | 69.11 | 16.32 |
| 3 | /b'/, /d'/ | 51 | 78.78 | 20.85 |
| 4 | /k'/, /ts/ | 43 | 91.08 | 18.15 |
| 5 | /b/, /d/ | 49 | 97.59 | 11.62 |
| 6 | /k/, /s/ | 51 | 128.90 | 21.97 |

Figure 6.55 Mean NQ at C1 plus and minus 1 standard deviation for all the consonant types.




Probably the most striking feature is the high value for /k/ and /s/, even though the standard deviation is relatively high; the next highest mean (97.59 for /b/ and /d/) being more than one standard deviation below. The means for the voiced /b/ and /d/ and ejective /k'/ and /ts/ are relatively close to each other. It is of interest that the mean value for ejectives is closer to the mean for /b/ and /d/ than to the other glottalic consonants /b'/ and /d'/, since /b'/ and /d'/ and /k'/ and /ts/ traditionally belong together as "glottalic", and, in a phonological feature analysis such as that of Halle and Stevens (1971), they would be grouped together as [+constricted glottis].

The means for /ʔ/ and /b'/ and /d'/ are very close and the standard deviations are relatively high. This makes it appear extremely unlikely that there is any statistically significant difference between them. (It should be remembered, however, that we do not have data for /ʔ/ from three speakers). On the other hand, the mean for /'y/ is lower and the standard deviation is smaller, which appears to support Lindau's suggestion that /'y/ shows a more extreme degree of laryngealization than the laryngealized stops. The degree of significance of this difference is suggested by the result of the one-way ANOVA (Table 6.9) with planned comparisons (Table 6.10). The ANOVA table is as follows; the high variance (F) ratio and the low p value indicate that there are differences between the groups (cf. Table 6.9).

Table 6.9: First ANOVA table for NQ at C1.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 5 | 88291.50 | 17658.30 | 47.98 | <.001 |
| Within groups | 220 | 80967.59 | 368.03 | | |
| Total | 225 | 169259.09 | | | |

Because the groups differ in size, the numbers of independent comparisons that can be made is limited. I have chosen to compare (1) /'y/ with /b'/ and /d'/ and (2) the ejectives with the plain voiced stops. The results are presented in Table 6.10. (Here, and in all subsequent tables presenting planned comparisons, estimates of degree of freedom have been rounded off to integers).

Table 6.10: Results of planned comparisons

| | Comparison | df | t | P |
|---|---|---|---|---|
| 1 | /'y/ vs /b'/ and /d'/ | 23 | -1.80 | .086 |
| 2 | /k'/, /ts/ vs /b/ and /d/ | 70 | -2.02 | .047 |

The p value for comparison 1 is higher than the commonly used critical value of .05, but is low enough to raise the question of whether a smaller value would have been obtained if there had been more /'y/ tokens in the data base or if I had been less conservative in eliminating outliers for /b'/ and /d'/ (in which case the standard deviation for this group would have been less). This leaves open the question of the relationship between /ʔ/ and these segments. Also, it must be remembered that NQ values for /'y/ (and /ʔ/) are vulnerable to the choice of consonant onset and offset positions as it has not always been easy to locate these boundaries. Thus we cannot give a definitive answer concerning the significance of the difference in mean NQ at C1 between the laryngealized oral stops and laryngealized palatal glide. Comparison 2 indicates a just-significant difference between the plain voiced and ejective consonants at the .05 level.

When the laryngealized consonants (/ʔ/, /'y/, /b'/ and /d'/) are grouped together and a second one-way ANOVA for NQ at C1 is carried out with a Scheffé multiple comparison test, the results are as follows (cf. Tables 6.11 and 6.12). This time there are four types, laryngealized, ejectives, plain voiced and voiceless.

Table 6.11: Second ANOVA table for NQ at C1.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 3 | 87317.63 | 29105.88 | 78.86 | <.001 |
| Within groups | 222 | 81941.46 | 369.11 | | |
| Total | 225 | 169259.09 | | | |

Table 6.12: Results of Scheffé multiple comparison.

| Group | Mean | Laryng. | Eject. | Voiced | Voiceless |
|---|---|---|---|---|---|
| 1 Laryng. | 76.68 | | | | |
| 2 Eject. | 91.08 | * | | | |
| 3 Voiced | 97.59 | * | | | |
| 4 Voiceless | 128.90 | * | * | * | |

(* denotes pairs for which p <.05.)

The laryngealized and the plain voiceless groups are each significantly different from the other three, but the Scheffé test does not indicate a significant difference with regard to NQ at C1 between ejectives and plain voiced stops. It should be noted that this test is conservative and that the significance level obtained in the t comparison was just under .05. Our conclusion must be that, with regard to NQ at the left of the consonant, voiced stops and ejectives in Hausa are close, though the possibility in ejectives of anticipatory low OQ phonation (as exemplified above in Fig. 6.40(a) **tsaatsàa**, speaker M7) does exist.

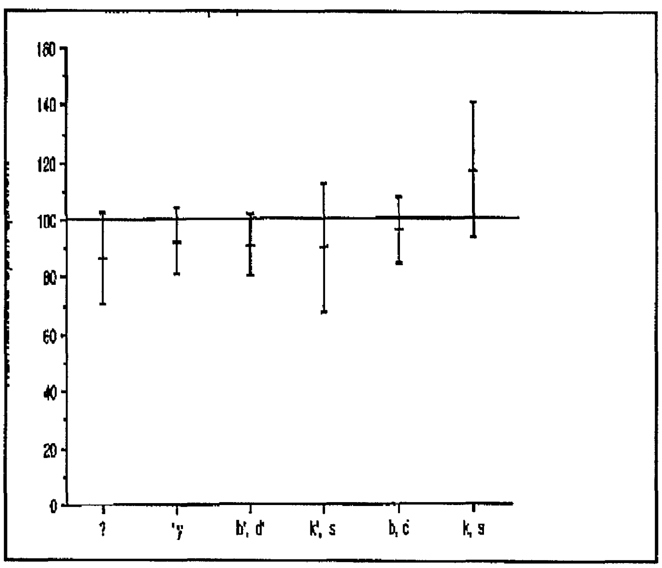
### 6.11.2 NQ at C2.

We begin by recalling our observation that the consonants appear to be more strongly differentiated at the left of the consonant (C1) than at the right (C2). See Table 6.13 and Fig. 6.56 which shows the NQ means and the standard deviations at position C2 for the various consonant types.

Table 6.13: Mean and standard deviation for NQ2 for the various consonant types.

| | Consonant Type | N | Mean | s.d |
|---|---|---|---|---|
| 1 | /ʔ/ | 10 | 86.66 | 16.32 |
| 2 | /'y/ | 13 | 92.52 | 11.65 |
| 3 | /b'/, /d'/ | 51 | 91.24 | 10.67 |
| 4 | /k'/, /ts/ | 43 | 90.21 | 22.26 |
| 5 | /b/, /d/ | 49 | 96.30 | 11.43 |
| 6 | /k/, /s/ | 51 | 117.29 | 23.55 |

Figure 6.56 shows the mean NQ at C2 plus and minus 1 standard deviation.



As in the case of C1, /k/ and /s/ show the highest mean value (117.29) with a high standard deviation. The next highest mean (96.30 for /b/ and /d/) is just under one standard deviation below. The mean for the ejectives is now within the range of the glottalic group (compare 90.21 for /k'/ and /ts/ with 91.24 for /b'/ and /d'/) and no longer closer to the mean for the plain voiced stops (cf. above). The standard deviation for this group is also high indicating a good deal of variation. The glottal stop shows the lowest mean (86.66) while the means for /'y/, /b'/ and /d'/ are very close.

Again a one-way ANOVA was carried out for NQ2 by consonant type (with six type categories as in Table 6.13). The table is as follows (cf. Table 6.14). Although the F ratio is large enough to indicate that the null hypothesis should be rejected (p <.001), as already noted, the resultant variance ratio (F) was found to be lower than for NQ at C1 (F=47.98). This indicates that the groups are less well differentiated by the variable NQ at C2.

Table 6.14: First ANOVA table for NQ at C2.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 5 | 26868.79 | 5373.76 | 17.66 | <.001 |
| Within groups | 220 | 66934.60 | 304.25 | | |
| Total | 225 | 99803.40 | | | |

When the laryngealized consonants are grouped together into a single group and a second ANOVA for NQ at C2 by consonant type (with four type categories) was carried out with a Scheffé multiple comparison test, only the plain voiceless stops group is recognized as significantly different with regards to NQ2 (cf. Tables 6.15 and 6.16). The results are as follows:

Table 6.15: Second ANOVA Table for NQ at C2.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 3 | 26508.78 | 8836.26 | 20.15 | <.001 |
| Within groups | 222 | 67294.62 | 303.13 | | |
| Total | 225 | 93803.39 | | | |

Table 6.16: Results of the Scheffé multiple comparison.

| Group | Mean | Laryng. | Eject. | Voiced | Voiceless |
|---|---|---|---|---|---|
| 1 Laryng. | 90.21 | | | | |
| 2 Eject. | 90.39 | | | | |
| 3 Voiced | 96.30 | | | | |
| 4 Voiceless | 117.29 | * | * | * | |

(* denotes pairs for which p < .05.)

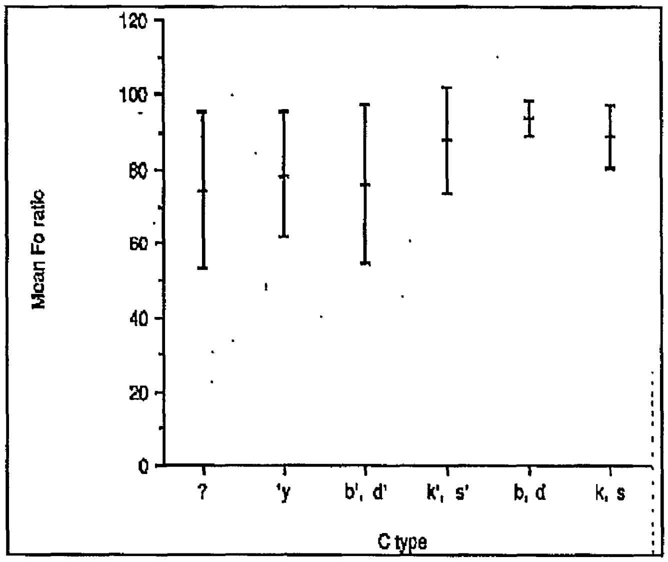
### 6.11.3 Fo at C1.

We begin by examining the means and standard deviations for FRAT1 for the various consonant groups. Table 6.17 and Fig. 6.57 show the mean and standard deviation for the ratio of FRAT1.

Table 6.17: Mean and standard deviation for the ratio of FRAT1.

| | Consonant type | N | Mean | s.d |
|---|---|---|---|---|
| 1 | /?/ | 19 | 74.59 | 20.97 |
| 2 | /'y/ | 13 | 78.75 | 16.84 |
| 3 | /b'/ and /d'/ | 51 | 76.02 | 21.50 |
| 4 | /k'/ and /ts/ | 43 | 87.97 | 13.81 |
| 5 | /b/ and /d/ | 49 | 93.93 | 4.61 |
| 6 | /k/ and /s/ | 51 | 89.08 | 8.18 |

Figure 6.57: Mean ratio for FRAT1.




Comparison of these figures with those in Table 6.20 below shows that, as in the case of OQ, a greater effect (i.e., greater deviation from 100) is exhibited at consonant onset than at consonant offset. The decrease is greater for the laryngealized consonants than for the ejectives, and greater for the ejectives than for the plain voiced consonants. The rather large decrease in mean Fo ratio before the plain voiceless consonants as shown in Fig. 6.57 can perhaps be related to their anticipatory voice quality effects: the marked lengthening of the open phase, in anticipation of the spread glottis during the consonant itself, may lengthen the whole period analogously to the increase in closed phase for the closed or constricted glottis of the glottalics. It should be noted, however, that, at the right of consonant (C2), high OQ is accompanied by high Fo ratio.

The fact that the lowest means for both NQ and FRAT are associated with the laryngealized consonants raises the question of the nature of the relationship between OQ lowering and Fo lowering in Hausa. Does greater OQ lowering involve greater Fo lowering for Hausa speakers? If so, we should expect a high correlation between OQ1 and FRAT1 for the laryngealized consonants. However, it is not the case that there is a high correlation between OQ and FRAT for the laryngealized consonants (cf. Figs. 6.58 and 6.59). Nor are the values particularly high if we apply the obvious transformation of putting one or both variables on a logarithmic scale. For the laryngealized consonants the correlation coefficient (r) for FRAT1 and NQ1 is .04; for log FRAT1 and NQ1 r = .03. For all consonant types, for FRAT1 and NQ1 r = .28; for log FRAT1 and NQ1 r = .28.

The interpretation becomes clearer when we consider Figs. 6.58 and 6.59, which show plots of NQ1 vs FRAT1 for the laryngealized consonants following low-tone and high- tone vowels. On both plots, we can imagine a diagonal line beginning at the origin (which is, of course, not shown) such that no observations fall below the line (i.e. in the bottom right corner) but there is considerable dispersion above the line (i.e. toward the upper left). This indicates that very low values of FRAT1 (below, say, 30 and 50) may be associated with relatively high NQ (above, say, 90%) but that the reverse does not occur; we do not have high FRAT1 with very low NQ1. For FRAT1 = 100, we would estimate minimum NQ1 at about 60 on both plots. These observations suggest the hypothesis that Fo lowering at the onset of the consonantal constriction might have equal or greater importance than OQ lowering (or, rather, its acoustic manifestation) as a cue in perception of these segments. Perceptual experiments would, of course, be necessary to test the hypothesis.

Comparison of the two plots is difficult because of the greater number of cases following high-tone vowels. However, if we estimate and draw in the y=x diagonal, it is apparent that a larger percentage of points lie below the y=x diagonal (i.e., have FRAT1 > NQ1) for consonants following high-tone vowels. This is perhaps surprising since one might expect greater drop in Fo following a vowel with higher Fo.

Figure 6.58 shows the plot of NQ1 vs FRAT1 for the laryngealized consonants following low tone vowels.

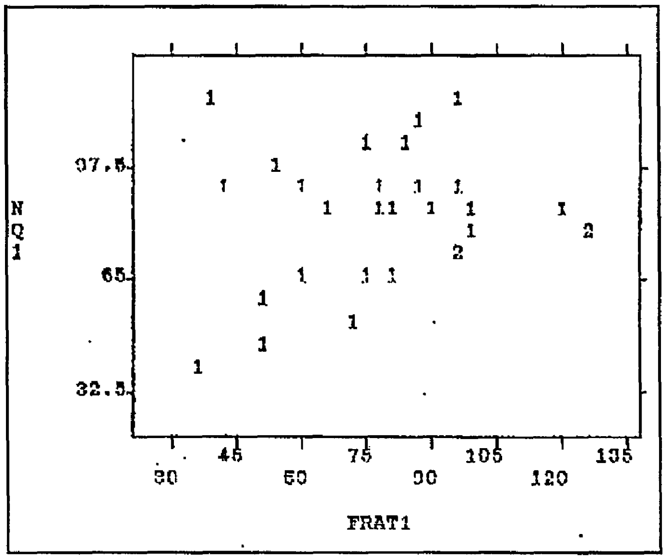
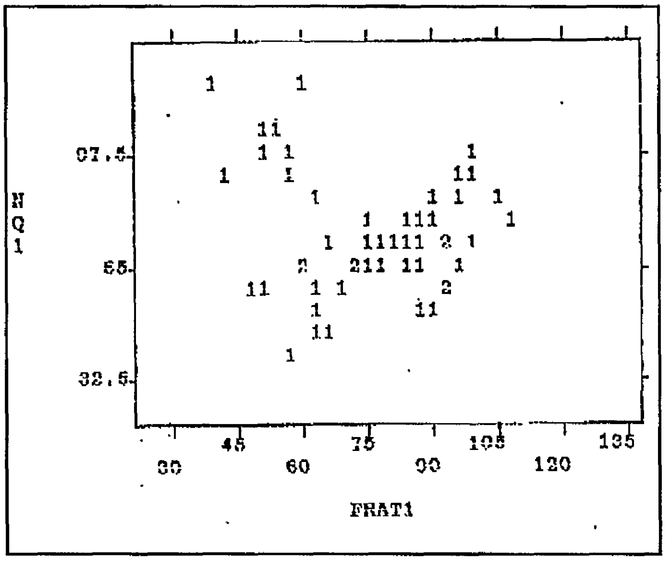



Figure 6.59 shows the plot of NQ1 vs FRAT1 for the laryngealized consonants following high tone vowels.




As in the case of NQ at C1, we group /ʔ/, /'y/, /b'/ and /d'/ together into a single laryngealized class. A one-way ANOVA is carried out for FRAT1 together with a Scheffé test. The results are as follows:

Table 6.18: ANOVA table for FRAT at C1.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 3 | 11681.22 | 3893.74 | 18.41 | <.001 |
| Within groups | 222 | 46945.16 | 211.46 | | |
| Total | 225 | 58626.38 | | | |

Table 6.19: Results of the Scheffé multiple comparison.

| Group | Mean | Laryn. | Eject. | Pl.v'less | Pl. v'd |
|---|---|---|---|---|---|
| 1 Laryn. | 76.12 | | | | |
| 2 Eject. | 87.97 | * | | | |
| 3 Pl. v'less | 89.08 | * | | | |
| 4 Pl. voiced | 93.93 | * | | | |

(* denotes pairs for which $p < .05$.)

A smaller variance ratio than obtained for NQ at C1 indicates that the groups are less well differentiated by this variable, confirming the impression made by Fig. 6.55 and 6.57 which show the relevant means and standard deviations. Similarly, the results of the Scheffé test above indicates that only the laryngealized group stands out as particularly distinct from the rest.

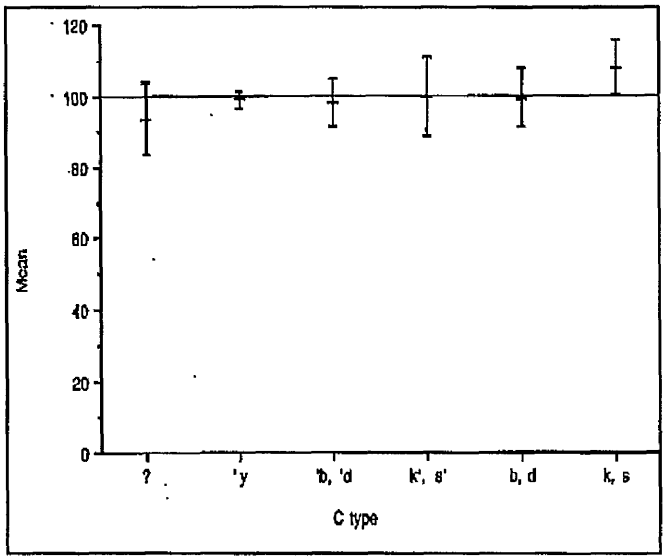
### 6.11.4 Fo at C2.

With regard to FRAT2, we begin by examining the means and standard deviations for the ratios of the various consonant types. See Table 6.20 and Fig. 6.60 which show the mean and standard deviation for FRAT2.

Table 6.20: Mean and standard deviation for FRAT2.

| | Consonant Type. | N | Mean | s.d |
|---|---|---|---|---|
| 1 | /?/ | 19 | 93.82 | 10.43 |
| 2 | /'y/ | 13 | 99.20 | 2.41 |
| 3 | /b'/ and /d'/ | 51 | 98.28 | 6.68 |
| 4 | /k'/ and /ts/ | 43 | 99.93 | 11.03 |
| 5 | /b/ and /d/ | 40 | 99.55 | 8.07 |
| 6 | /k/ and /s/ | 51 | 108.17 | 7.62 |

Figure 6.60: Mean ratio of FRAT2.




A glance at the table and the figure show that the main striking feature here is the high mean FRAT2 for the plain voiceless group (108.17) as compared with the others. The mean Fo ratio values for all the other groups are close to 100, indeed all the other means lie between 98 and 100 with the exception of the /?/ for which the mean FRAT2 is 93.82.

As in the case of NQ2 we grouped the consonants into four classes and carried out a one-way ANOVA for FRAT2 together with a Scheffé test. The results are as follows:

Table 6.21: ANOVA table for FRAT at C2.

| Source of Variation | df | S.Squares | Mean Squares | F | p |
|---|---|---|---|---|---|
| Between groups | 3 | 3823.28 | 1274.43 | 17.98 | <.001 |
| Within groups | 222 | 15731.30 | 70.86 | | |
| Total | 225 | 19554.58 | | | |

Table 6.22: Results of the Scheffé multiple comparison.

| Group | Mean | Laryng. | Eject. | Voiced | Voiceless |
|---|---|---|---|---|---|
| 1 Laryng. | 97.42 | | | | |
| 2 Eject. | 99.53 | | | | |
| 3 Voiced | 99.55 | | | | |
| 4 Voiceless | 108.17 | * | * | * | |

(* denotes pairs for which p < .05.)

A smaller variance ratio shows that as in the case of NQ2, the groups are less well differentiated by this variable, confirming the impression made by Fig. 6.60 which shows the means and standard deviations. Furthermore, the results of the Scheffé test indicate that only the plain voiceless stops group stands out as particularly distinct from the rest.

### 6.11.5 Single Consonants: Summary.

Our discussion of results has focused on comparison of the beginning and the end of the consonantal constriction (points C1 and C2) for the various consonant types. With regard to normalized open quotient (NQ1, NQ2), the consonant types are more strongly differentiated at the beginning (C1) than at the end (C2), though the plain voiceless type shows distinctively high NQ at C2. With regard to Fo movement, the laryngealized consonants are characterized by a marked drop in Fo at C1, while the plain voiceless consonants are characterized by raised Fo at C2. We have suggested that these Fo movements may be important perceptually.

In the set of "laryngealized consonants", we have included not only /b'/ and /d'/ but also /'y/ and /?/. The question of whether or not /'y/ is produced with a more extreme degree of laryngealization as claimed by Lindau (1984) has been left open. In any case, /'y/, /ʔ/, /b'/ and /d'/ all share low NQ and lowered Fo at the beginning of the consonantal constriction, which distinguishes them from the other types. All this is consistent with the results of our qualitative analysis (see section 6.8.2 for qualitative analysis of /b'/ and /d'/).

The ejectives are of some interest because they stand out as distinct from the laryngealized consonants with regard to both NQ and Fo movement at C1. This is somewhat surprising since a simultaneous glottal stop is necessary for the production of an ejective. Of course, there is a good deal of variability in the data, and as already pointed out, marked OQ lowering (i.e. low NQ) at C1 is observed for some tokens. However, these are balanced by other tokens with relatively high NQ at C1. It is tempting to relate the relatively high mean NQ1 to the suggestion of Ingram and Rigsby (1987) that Hausa ejectives are of the "lax" type. Unfortunately, I have not listened to tokens with high NQ1 to see if these sound particularly weak, although we shall see that the geminate ejectives show lower mean NQ at C1.

Finally, we may note that our results concerning Fo movements class Hausa with languages in which [ʔ] lowers the Fo of preceding vowel (Hombert et al. 1979). This, though perhaps unusual, is consistent with the observed affinity of glottal stop and laryngealization in the language. Some lowering of Fo (relative to the preceding vovel) is observed for all the consonant types.

## 6.12 Single vs Geminate Consonants.

### 6.12.1 Introduction.

As mentioned earlier, not all speakers recorded the geminates. Our comparisons in this section are based on the data from those speakers who recorded single and geminate consonants (M1, M3, M4, M7, M8, M10, M12, M14, M15).

Consider Figs. 6.61-6.64, which show mean NQ values across speakers at the four positions, Pre, C1, C2, and Post. Fig. 6.61 presents data for /b'b'/ and /d'd'/, Fig. 6.62 for /k'k'/ and /tts/, Fig. 6.63 for /bb/ and /dd/, and Fig. 6.64 for /kk/, /ss/ and /tt/. The vertical lines show one standard deviation above and below the mean. As in the case of the single consonants, mean NQ decreases between Pre and C1 for the glottalic and plain voiced consonants; /b'b'/ and /d'd'/ show the greatest decrease while /bb/ and /dd/ show the least, staying near the modal value (100). For the plain voiceless consonants, NQ increases. Figs. 6.65-6.66 present comparisons between the four geminate categories with regard to FRAT1 and FRAT2.

Figure 6.61 shows mean NQ by consonant position for the geminates /b'b'/ and /d'd'/ plus and minus one standard deviation.

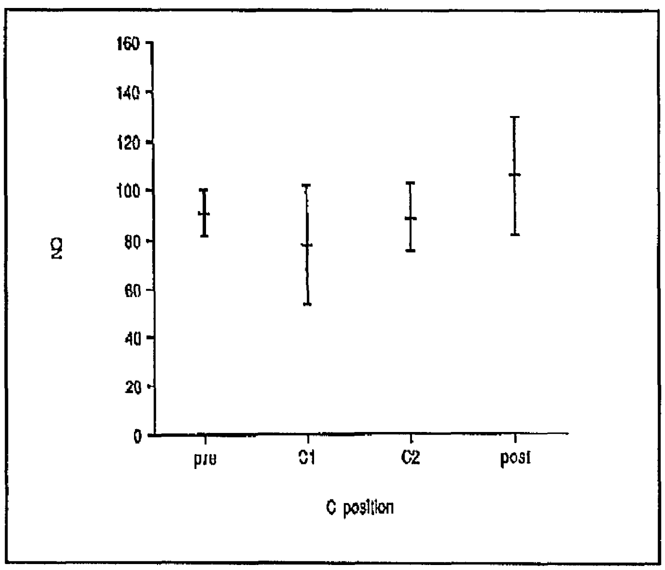


Figure 6.62 shows mean NQ by consonant position for the geminates /tts/ and /k'k'/ plus and minus one standard deviation.

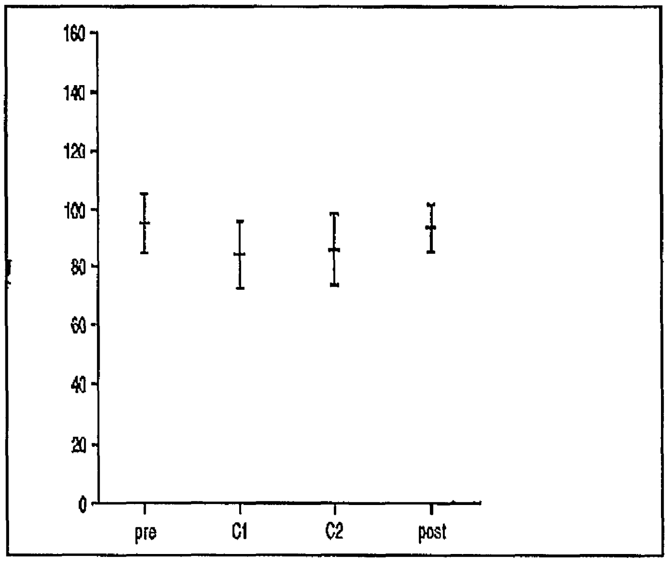



Figure 6.63 shows mean NQ by consonant position for the geminates /bb/ and /dd/ plus and minus one standard deviation.

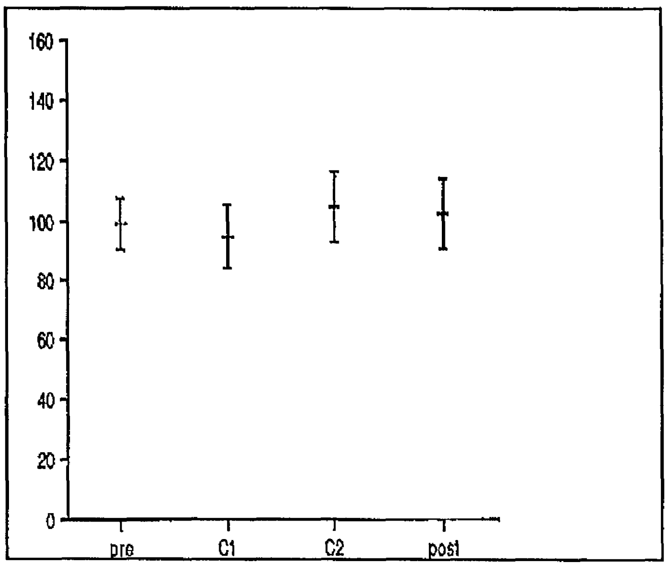


Figure 6.64 shows mean NQ by consonant position for the geminates /kk/, /ss/ and /tt/ plus and minus one standard deviation.

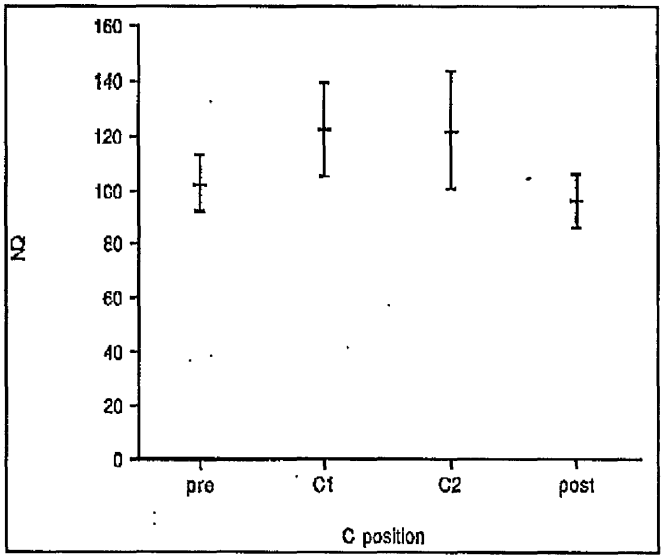



Figure 6.65 illustrates the mean ratios of Fo at C1 to maximum Fo between pre and C1.

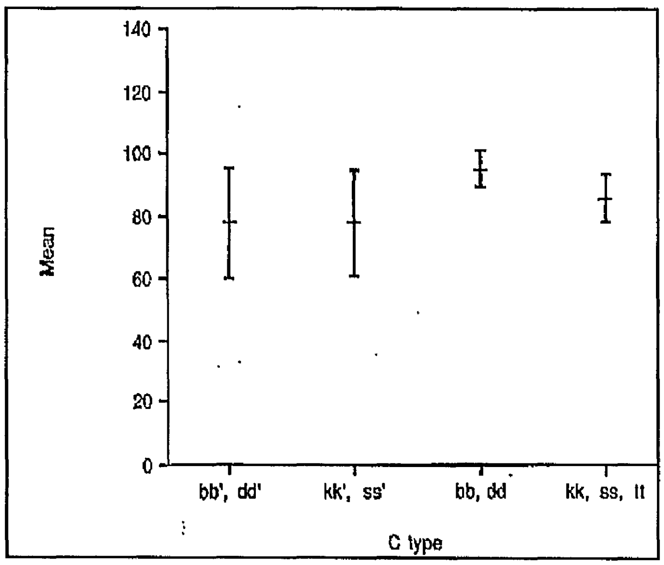
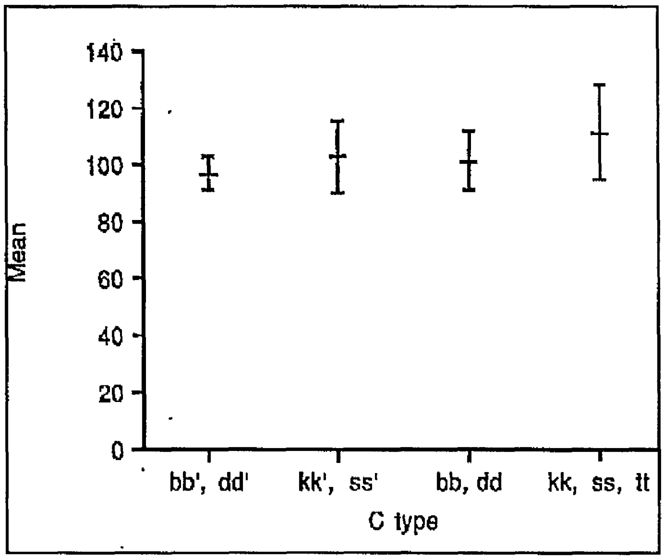


Figure 6.66 illustrates the mean ratios of Fo at C2 to maximum Fo between C2 and post.




6.12.2 NQ at C1.

Table 6.23 presents means and standard deviations for NQ for single and geminate consonants. It should be noted that, in the case of single consonants, the "laryngealized" group includes only /b'/ and /d'/ (not /?/ or /'y/).

Table 6.23: Means and standard deviations for NQ1 for the single and geminate consonants for speakers who recorded both singles and geminates.

| | | Singles | | | Geminates. | | |
|---|---|---|---|---|---|---|---|
| Consonant Type | | N | Mean | s.d. | N | Mean | s.d. |
| 1 | Laryngealized | 36 | 80.28 | 18.00 | 17 | 77.46 | 24.86 |
| 2 | Ejective | 30 | 93.48 | 19.54 | 19 | 84.32 | 11.82 |
| 3 | Pl. voiced | 34 | 100.46 | 10.50 | 18 | 94.40 | 11.07 |
| 4 | Pl. voiceless | 36 | 132.70 | 23.14 | 26 | 122.30 | 16.93 |

The laryngealized, ejective, and plain voiced geminate consonants all show lower mean NQ values, involving greater deviation from the modal (100) than their single counterparts. The difference between mean values is greatest for the ejectives (9.16) and least for the laryngealized stops (2.82). The laryngealized stops, both single and geminate, have high standard deviations: thus, we do not expect the difference between these two groups to be statistically significant.

In the case of plain voiceless consonants, the mean NQ value for the geminates is also less, but this time a smaller deviation from modal (100) is involved. The difference between mean values (10.40) is slightly larger than for the ejectives.

A one-way ANOVA (with 8 groups) was carried out with comparisons between singles and corresponding geminates. The results are presented in Tables 6.24 and 6.25. For the ejectives and plain voiceless categories, the **p** values are below the .05 critical level; for the plain voiced category, **p** is relatively small, though greater than .05.

As regards the comparisons, see table 6.25 which give the results.

Table 6.24: ANOVA table between single and geminate consonants for NQ at C1.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 7 | 95022.04 | 13574.58 | 38.84 | .001 |
| Within groups | 232 | 81063.65 | 349.41 | | |
| Total | 239 | 176085.79 | | | |

Table 6.25: Results of the comparisons.

| | Comparison | | df | t | p |
|---|---|---|---|---|---|
| 1 | /b'/ and /d'/ | vs /b'b'/ and /d'd'/ | 23 | .07 | .947 |
| 2 | /ts/ and /k'/ | vs /tts/ and /k'k'/ | 47 | 2.05 | .047 |
| 3 | /b/ and /d/ | vs /bb/ and /dd/ | 33 | 1.88 | .069 |
| 4 | /k/ and /s/ | vs /kk/ and /ss/ | 60 | 2.04 | .045 |

6.12.3 NQ at C2.

Table 6.26 presents means and standard deviation for NQ2 for single and geminate consonants. Again, the difference between means for single and geminate laryngealized is small (.86). In the case of the ejectives, the geminates still show a lower mean value, but the difference between the means (4.28) is less than for NQ1. The mean values for single and geminate plain voiceless consonants are very close, with a difference of only .27.

The plain voiced consonants differ from all the rest in that the relationship between singles and geminates appears to be the reverse of that observed at C1 (see Table 6.23). This time, the mean NQ value for the geminate consonants is higher. The difference between single and geminate means is about the same for NQ1 (6.06) and NQ2 (6.73), and the standard deviations look comparable.

Table 6.26: Mean NQ values and the standard deviation at position C2 for the various consonant types.

| | | Singles | | | Geminates. | | |
|---|---|---|---|---|---|---|---|
| | Consonant Type | N | Mean | s.d. | N | Mean | s.d. |
| 1 | Laryngealized | 36 | 92.00 | 10.84 | 17 | 91.14 | 13.61 |
| 2 | Ejective | 30 | 89.88 | 13.04 | 19 | 85.60 | 12.40 |
| 3 | Pl. Voiced | 34 | 98.44 | 11.66 | 18 | 105.17 | 11.22 |
| 4 | Pl. Voiceless | 36 | 121.98 | 25.32 | 27 | 121.71 | 21.00 |

As before, a one-way ANOVA (with 8 groups) was carried out with comparisons between singles and geminates. The results are presented in Tables 6.27 and 6.28. As would be expected, the differences between singles and geminates do not appear to be statistically significant for the laryngealized, ejective, and plain voiceless categories. For the plain voiced category, the result is again borderline, with **p** = .05.

Table 6.27: ANOVA table between single and geminate consonants for NQ at C2.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 7 | 44292.15 | 6327.45 | 24.22 | .001 |
| Within groups | 233 | 60847.89 | 261.15 | | |
| Total | 240 | 105140.04 | | | |

Table 6.28: Results of the comparisons.

| | Comparison | | df | t | p |
|---|---|---|---|---|---|
| 1 | /b'/ and /d'/ | vs /b'b'/ and /d'd'/ | 25 | .16 | .874 |
| 2 | /ts/ and /k'/ | vs /tts/ and /k'k'/ | 40 | 1.13 | .267 |
| 3 | /b/ and /d/ | vs /bb/ and /dd/ | 36 | 2.03 | .050 |
| 4 | /k/ and /s/ | vs /kk/ and /ss/ | 60 | .05 | .963 |

6.12.4 Fo at C1.

Table 6.29 presents means and standard deviations for FRAT1 for the single and geminate consonants. For the laryngealized and plain voiced categories, the difference between means for the singles and geminates are small (1.29 and .08 respectively). For the ejectives, the difference between means is relatively large (9.73), comparable in magnitude to the difference in means for NQ1 (9.16, see Table 23). This again suggests a relationship between OQ lowering and Fo (see 6. 11.3 above); as the standard deviations are relatively high, a more detailed examination of the data would be desirable.

In the case of plain voiceless consonants, mean FRAT1 is lower for the geminates than for the singles, and mean NQ1 is lower (Table 6.23). This makes the explanation of Fo lowering before these consonants proposed in section 6.11.3 appear less attractive. If lengthening the open phase, in anticipation of the spread glottis during the consonant itself, results in lengthening of the whole period, then we

Table 6.29: Means and standard deviations for the ratio FRAT1.

| | | Singles | | | Geminates | | |
|---|---|---|---|---|---|---|---|
| | Consonant Type | N | Mean | s.d. | N | Mean | s.d. |
| 1 | Laryngealized | 36 | 76.50 | 22.04 | 17 | 77.79 | 17.30 |
| 2 | Ejective | 30 | 87.18 | 15.86 | 19 | 77.45 | 16.87 |
| 3 | Pl. voiced | 34 | 94.20 | 4.85 | 18 | 95.00 | 5.67 |
| 4 | Pl. voiceless | 36 | 90.15 | 8.77 | 26* | 85.43 | 7.87 |

* No FRAT1 or NOQ1 for case 126 (geminate).

should expect to observe **higher** FRAT1 with **lower** NQ1 (which indicates less open phase lengthening). Because the standard deviations for NQ1 are so high, a more detailed examination of the data would be desirable.

As before, a one-way ANOVA (with 8 groups) was carried out with comparisons between singles and geminates. The results are presented in Tables 6.30 and 6.31. As would be expected, the differences between singles and geminates do not appear to be significant for the laryngealized and plain voiced categories. For the ejectives, the result is only borderline with **p** = .052, despite the rather large difference between the means; this must be due to the rather large degree of variability as reflected in the standard deviations. For the plain voiceless category, the difference between singles and geminates does appear to be significant, with **p** = .031.

Table 6.30: ANOVA table between single and geminate consonants for FRAT at C1.

| Source of Variation | df | S.Squares | Mean Squares | F | p |
|---|---|---|---|---|---|
| Between groups | 7 | 1.2385 | .1760 | 8.30 | .0 |
| Within groups | 232 | 4.9435 | .0213 | | |
| Total | 239 | 6.1820 | | | |

The results of the comparisons are as follows:

Table 6.31: Results of the comparisons.

| | Comparison | | df | t | p |
|---|---|---|---|---|---|
| 1 | /b'/ and /d'/ | vs /b'b'/ and /d'd'/ | 31 | .31 | .762 |
| 2 | /ts/ and /k'/ | vs /tts/ and /k'k'/ | 37 | 2.01 | .052 |
| 3 | /b/ and /d/ | vs /bb/ and /dd/ | 30 | .45 | .653 |
| 4 | /k/ and /s/ | vs /kk/ and /ss/ | 57 | 2.22 | .031 |

### 6.12.5 Fo at C2.

Table 6.32 presents means and standard deviations for FRAT2 for single and geminate consonants. The difference between means is largest for plain voiceless consonants (3.63). It is unlikely that this is statistically significant, as the standard deviation for the geminates is relatively large. See Fig. 6.66 above.

Table 6.32: Means and standard deviations for the ratio FRAT2.

| | | Singles | | | Geminates | | |
|---|---|---|---|---|---|---|---|
| Consonant Type | | N | Mean | s.d. | N | Mean | s.d. |
| 1 | Laryngealized | 36 | 97.56 | 7.34 | 17 | 96.48 | 5.83 |
| 2 | Ejective | 30 | 101.99 | 11.34 | 19 | 102.67 | 12.80 |
| 3 | Pl. voiced | 34 | 98.66 | 9.10 | 18 | 100.71 | 10.47 |
| 4 | Pl. voiceless | 36 | 107.65 | 7.61 | 27 | 111.28 | 16.87 |

Again a one way ANOVA was carried out, with comparisons between corresponding singles and geminates (cf. Tables 6.33 and 6.34). As would be expected, none of the differences appears to be statistically significant.

Table 6.33: ANOVA table between single and geminate consonants for FRAT at C2.

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between groups | 7 | .6057 | .0865 | 7.94 | .001 |
| Within groups | 233 | 2.5382 | .0100 | | |
| Total | 240 | 3.1439 | | | |

Table 6.34: Results of the comparisons.

| | Comparison | | df | t | p |
|---|---|---|---|---|---|
| 1 | /b'/ and /d'/ | vs /b'b'/ and /d'd'/ | 37 | .13 | .894 |
| 2 | /ts/ and /k'/ | vs /tts/ and /k'k'/ | 35 | .19 | .851 |
| 3 | /b/ and /d/ | vs /bb/ and /dd/ | 31 | .70 | .480 |
| 4 | /k/ and /s/ | vs /kk/ and /ss/ | 34 | 1.05 | .306 |

### 6.12.6 Single vs. Geminate Consonants: Summary.

The results of the comparisons between single and geminate consonants are summarized in Table 6.35. The symbol "<" indicates that the mean value for the geminates is less than the mean value for the single consonants, the symbol

">" indicates that the mean value for the geminates is greater than the mean value for the single consonants, and the symbol "≈" indicates that the difference between the two means is less than 2. A "*" indicates that the difference between the two means is significant at the .05 level, while "(*)" marks cases for which $.05 \leq p < .1$.

Table 6.35: Comparison of mean values for geminate consonants with mean values for single consonants for the variables NQ1, NQ2, FRAT1 and FRAT2.

| | | C1 | | C2 | |
|---|---|---|---|---|---|
| | | NQ1 | FRAT1 | NQ2 | FRAT2 |
| 1 | Larygealized | < | ≈ | ≈ | ≈ |
| 2 | Ejective | <* | <(*) | < | ≈ |
| 3 | Pl. Voiced | <(*) | ≈ | >(*) | > |
| 4 | Pl. Voiceless | <* | <* | ≈ | > |

In the case of the laryngealized consonants, we have not found any significant difference between singles and geminates for our four variables. We have already noted the similarity between the single laryngealized consonants and the glottal stop; presumably the geminates are produced by simply lengthening both glottal gesture and the oral closure, and there is no difficulty maintaining the same relative timing. It would be interesting to investigate air flow characteristics of these consonants to discover whether any ingressive air flow occurred (which would suggest lowering of the larynx).

For ejectives, the geminates show both lower OQ and lower Fo at the onset of the occlusion. Mean NQ1 is thus closer to mean NQ1 for the laryngealized stops (and for the glottal stop) than to mean NQ1 for the plain voiced stops. This suggests that the initial glottal closure is (on average) stronger for geminates than for singles. We should like to interpret this as indicating that the geminate ejectives are not so subject to "weak" articulation as single ejectives - a phenomenon well-attested for other consonant types. One question which remains concerning these consonants is the relative timing of glottal raising and oral closing gestures.

For the plain voiced stops, geminates show lower mean NQ at the left of the consonant (C1) and higher mean NQ at the right (C2); at both positions, they depart further from the modal value (100). If we now subtract NQ1 from NQ2 for individual tokens we find that mean (NQ2 - NQ1) is 10.20 for the geminates (s.d. = 13.34) but only -.27 for the singles. A t-test indicates that the difference between singles and geminates is highly significant (t = -3.22, p = .003, 26 d.f.). In computing these values one outlier was left out of account (speaker M14, fad'àɑ̦;OQ1 = 62, OQ2 = 28, AVOQ for this speaker is 56.50).

It is difficult to see why the geminates should show rising NQ. Presumably, lower OQ at the onset of the occlusion means that air passes into the supraglottal cavity at a slower rate, thereby making it possible to maintain a pressure drop across the glottis longer. However, this does not explain why OQ should be higher at the right of the consonant. The higher OQ at C2 is consistent with the suggestion of Halle and Stevens (1967), referred to in Chomsky and Halle (1968:301) that, for sounds other than vowels,

> "periodic vocal cord vibrations can be maintained only if the width of the glottal pulse is increased by lengthening the open phase during each glottal vibration over that normally found in vowels and/or if damping of the first formant is substantially increased by creating larger glottal opening"

Our results are, of course, only borderline with regard to statistical significance. Some cross-linguistic data would be of interest here as well.

For the plain voiceless stops, the geminates show less OQ raising at the left of the consonant than their single counterparts. This may be explained with reference to the relative timing of oral closing and glottal gestures. If the closure is longer, then presumably more of the glottal opening gesture will take place during this period. The oral closing gesture will occur earlier relative to the glottal opening gesture. Data on the duration of the consonants is presented in section 6.14.

## 6.13 Other Sources of Variation in the Data.

In the above discussion, we have often had occasion to note that the standard deviations for particular variables are rather high. It is therefore worth considering other possible sources of variation in the data. We shall confine our analysis here to the case of NQ1 for single consonants (see section 6.11.1).

One possibility is that our groupings are too general - i.e. that we should have separated /b'/ and /d'/, /k/ and /s/, etc. Table 6.36 presents means and standard deviations for individual consonants; these may be compared with the means and standard deviations for the groupings.

Table 6.36: Means and standard deviations for NQ1 for individual consonants and consonant groupings.

| | Individual Consonants | | | Groupings | | |
|---|---|---|---|---|---|---|
| Consonant | N | Mean | s.d | N | Mean | s.d |
| /b'/ | 27 | 79.74 | 17.90 | 51 | 78.78 | 20.85 |
| /d'/ | 24 | 77.70 | 24.09 | | | |
| /k'/ | 22 | 91.36 | 13.86 | 43 | 91.08 | 18.15 |
| /ts/ | 21 | 90.79 | 22.14 | | | |
| /b/ | 24 | 99.35 | 10.44 | 49 | 97.59 | 11.62 |
| /d/ | 25 | 95.91 | 12.63 | | | |
| /k/ | 26 | 125.03 | 20.29 | 51 | 128.90 | 21.97 |
| /s/ | 25 | 132.92 | 23.30 | | | |

There are some observations of interest to be made here - for example, the standard deviation for /d'/ is higher than that for /b'/ despite the fact that the /d'/s seemed to be more consistent in the qualitative analysis. As might be expected, the mean value for /s/ is higher than the mean value for /k/. However, we shall simply note that, for every grouping, the standard deviation is between the standard deviations for the individual consonants; adopting a finer classification does not result in less variation within each group.

Another possible source of variation is between speakers. By using normalized open quotient rather than absolute open quotient in our analysis, we hoped to reduce the effect of variation between speakers with regard to modal OQ. However, the speakers may still differ, e.g. as to whether their laryngealization is "strong" or "weak"; that such effects do exist is clear from the diagrams such as Figs. 6.49-6.51.

In order to evaluate the variation between speakers, a two-way Analysis of Variance was carried out (cf. Table 6.37) for NQ1 by consonant type (with four groups, laryngealized, ejective, plain voiced and plain voiceless) and speaker. There are, of course, difficulties here because the groups are not equal in size. Still, we may note that the interaction term is highly significant. The nature and extent of the differences between consonant types varies from speaker to speaker.

Table 6.37: ANOVA Table: NQ1 by consonant type and speaker (single consonants).

| Source of Variation | df | S.Squares | Mean Squares | F | P |
|---|---|---|---|---|---|
| Main Effects | 15 | 106096.33 | 7073.09 | 30.57 | <.001 |
| Cons type | 3 | 88086.46 | 29362.15 | 126.89 | <.001 |
| Speaker | 12 | 18778.69 | 1564.89 | 6.73 | <.001 |
| Interaction | 36 | 22899.33 | 636.09 | 2.75 | <.001 |
| Explained | 51 | 128995.66 | 2529.33 | 10.93 | <.001 |
| Residual | 174 | 40263.44 | 231.40 | | |
| Total | 225 | 169259.10 | 752.26 | | |

## 6.14 Measurement of Duration.

### 6.14.1 Introduction.

Now we shall compare the various consonant types with regard to closure duration and VOT (where applicable). As mentioned above, no definitive statement can be made here as regards consonant duration due to the following reasons:

1. no attempt was made in the study to control the rate of speaking of individual speaker;
2. there is considerable variation in the data in both word length and phonological vowel length;
3. as noted above, the various speakers are very unevenly represented; and
4. the duration measurements (particularly in the segments /'y/, /ʔ̱/, /b'/, /d'/ and the plain voiced segments) may not be taken to be exact as it is not always possible to mark the beginning and the end of the segments.

However, the results give us some idea of some of the differences between the segments.

The individual closure durations and VOT values (where appropriate) for each speaker and for all speakers pooled together are tabulated in Tables 6.38-42. Ratios giving comparisons of plain consonants with their glottalic counterparts and of single consonants with their geminate counterparts are also given.

### 6.14.2 /b'/, /d'/, /b/ and /d/.

Meyers (1976) measured the duration of the glottalic and non-glottalic consonants and compared the results. She found that the closure durations of the glottalic stops were longer than those of their non-glottalic counterparts.

In agreement, I found that the glottalic stops are longer than the plain stops. The results show that the bilabial and the alveolar glottalic stops were longer for 15 of the 16 speakers for the bilabial and 14 of the 15 speakers for the alveolar. See Table 6.38 (for the bilabial) and Table 6.39 (for alveolar).

Hausa single stops have been the subject of numerous experimental studies, but none of these to my knowledge has been concerned with the relative duration of geminates compared to their single counterparts. Here a comparison is made between the singles and the geminates. My data show that geminates (both glottalic and non-glottalic) are markedly longer than their single counterparts (cf. Tables 6.38 and 6.39). However, there is considerable variation between speakers as regards the magnitude of the ratio. For seven out of twelve speakers the ratio /b'b'/: m(b') (mean value for /b'/) is greater than the ratio /bb/: m(b) but the ratio /d'd'/: m(d') is greater than /dd/: m(d) for only three out of the twelve speakers.

Table 6.38: Durations, mean durations and duration ratios for the bilabial stops.

| Durations and mean durations (in msec) | | | | | | | Ratios | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Spk | /b'/ | M | /b/ | M | /b'b'/ | /bb/ | M./b'/ / M./b/ | ./b'b'/ / ./bb/ | ./b'b'/ / M./b'/ | ./bb/ / M./b/ |
| M1 | 117,- | 117 | 74,- | 74 | - | - | 1.58 | - | - | - |
| M2 | 101,82 | 91.5 | 83,92 | 87.5 | 181 | 146 | 1.09 | 1.23 | 1.97 | 1.66 |
| M3 | 109,92 | 100.5 | 79,84 | 81.5 | 157 | 168* | 1.23 | 0.93 | 1.56 | 2.06 |
| M4 | 106,108 110 | 108 | 80,- | 80 | 216 | 144 | 1.35 | 1.5 | 2.00 | 1.80 |
| M5 | 108,118 | 113 | 97,87 | 92 | - | - | 1.23 | - | - | - |
| M6 | 90,95, 120,126 | 107.8 | 112,86 | 99 | 200 | 182 | 1.08 | 1.09 | 1.85 | 1.83 |
| M7 | 103,124 | 113.5 | 86,105 | 95.5 | 187 | 168 | 1.18 | 1.11 | 1.64 | 1.75 |
| M8 | 117,141 | 129 | 99,122 | 110.5 | 236 | 168 | 1.16 | 1.40 | 1.82 | 1.52 |
| M9 | 79,91 | 85 | 102,97 | 99.5* | - | - | 0.85 | - | - | - |
| M10 | 139,155 | 147 | 103,110 | 106.5 | 211 | 179 | 1.38 | 1.17 | 1.43 | 1.68 |
| M11 | 97,115 | 106 | 68,86 | 77 | 145 | 208* | 1.37 | 0.69 | 1.36 | 2.70 |
| M12 | 110,98 | 104 | 102,- | 102 | 164 | 143 | 1.02 | 1.14 | 1.57 | 1.40 |
| M13 | 114,126 | 120 | 89,100 | 94.5 | - | - | 1.26 | - | - | - |
| M14 | 101,169 | 135 | 113,115 | 114 | 202 | 159 | 1.18 | 1.27 | 1.49 | 1.39 |
| M15 | 91,108 | 99.5 | 74,86 | 80 | 204 | 190 | 1.24 | 1.07 | 2.05 | 2.37 |
| F1 | 97,93 | 95 | 63,- | 63 | 324 | 134 | 1.50 | 2.41 | 3.41 | 2.12 |
| ASP | - | 111 | - | 91 | 202.2 | 165.7 | 1.21 | 1.22 | 1.82 | 1.82 |

NOTE:
* means that non-glottalic stop is either longer than glottalic or equal.
ASP means all speakers pooled together.
M means mean.

Table 6.39: Durations, mean durations and duration ratios for the alveolar stops.

| Durations and mean durations (in msec) | | | | | | | Ratios | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Spk | /d'/ | M | /d/ | M | /d'd'/ | /dd/ | M./d'/ / M./d/ | ./d'd'/ / ./dd/ | ./d'd'/ / M./d'/ | ./dd/ / M./d/ |
| M1 | - | - | - | - | - | - | - | - | - | - |
| M2 | 78,92 | 85 | 73,85 | 79 | 189 | 155 | 1.07 | 1.21 | 2.22 | 1.96 |
| M3 | 82,83 | 82.5 | 71,58 | 64.5 | 231 | 260* | 1.27 | 0.88 | 2.80 | 4.03 |
| M4 | 84,115 | 99.5 | 60,78 | 69 | 183 | 148 | 1.44 | 1.23 | 1.83 | 2.14 |
| M5 | 178,129 | 153.5 | 98,- | 98 | - | - | 1.56 | - | - | - |
| M6 | 73,104 | 88.5 | 58,- | 58 | - | - | 1.52 | - | - | - |
| M7 | 87,99 | 93 | 78,94 | 86 | 185 | 158 | 1.08 | 1.17 | 1.94 | 1.83 |
| M8 | 101,116 | 108.5 | 87,99 | 93 | 110 | 201* | 1.16 | 0.54 | 1.01 | 2.16 |
| M9 | 89,84 | 86.5 | 84,88 | 86 | - | - | 1.00 | - | - | - |
| M10 | 115,90 | 102.5 | 94,106 | 100 | 239 | 255* | 1.02 | 0.93 | 2.33 | 2.55 |
| M11 | 84,73 | 78.5 | 105,66 | 85.5* | 168 | - | 0.91 | - | 2.14 | - |
| M12 | 81,104 | 92.5 | 46,59 | 52.5 | 201 | 145 | 1.76 | 1.38 | 2.17 | 2.76 |
| M13 | 122,97 | 109.5 | 104,95 | 99.5 | - | - | 1.10 | - | - | - |
| M14 | 116,140 | 128 | 86,98 | 92 | 214 | 147 | 1.40 | 1.45 | 1.67 | 1.59 |
| M15 | 95,110 | 102.5 | 67,74 | 70.5 | 171 | 160 | 1.45 | 1.06 | 1.66 | 2.26 |
| F1 | 73,92 | 82.5 | 50,98 | 74 | - | 183 | 1.11 | - | - | 2.47 |
| ASP | - | 99.5 | - | 80.5 | 189.1 | 181.2 | 1.23 | 1.04 | 1.90 | 2.25 |

NOTE:
* means that non-glottalic stop is either longer than glottalic or equal.
ASP means all speakers pooled together.
M means mean.
\+ means two figures (144,170) averaged.

### 6.14.3 /ts/ and /s/.

No attempt was made by early studies (Carnochan (1952), Ladefoged (1968), Meyers (1976) and Lindau (1984)) to provide duration data on /ts/. Since there is considerable variation in my data in both word length and phonological vowel length, relatively little can be concluded here as to consonant duration. However, the single glottalic consonant is found to be shorter than the non-glottalic one. Its mean duration was 113.9 msec (N=24) while the mean for the non-glottalic /s/ was 123.5 msec (N=27), see Table 6.40. Comparing the mean duration for single glottalic and non-glottalic segments I found that 10 speakers out of 14 produced longer non-glottalic stops.

As in the case of the stops, it was found that the glottalic geminates are considerably longer than the single glottalic affricate for all speakers, sometime more than twice as long (cf. speaker M3, Table 6.40). When the geminate glottalic affricate was compared with the corresponding non-glottalic, it was found that the glottalic consonant was longer for all speakers but one (M2). For seven out of nine speakers, the ratio /tts/: m(ts) is longer than the ratio /ss/: m(s).

#### 6.14.3.1 VOT.

VOT was measured for /ts/, /tts/ and /tt/. Since the single voiceless alveolar stop /t/ was not recorded, results were compared between the geminates only. It was found that the VOT of the glottalic consonant /tts/ is longer, averaging 49.6 msec compared to 25.4 msec for the plain (cf. Table 6.40).

Table 6.40: Durations, mean, mean VOT, and duration ratios for the alveolar affricate ejective, voiceless stop and voiceless fricative.

| Durations and mean durations (in msec) | | | | | | | | | | | Ratios | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spk | /ts/ | M | vot | /s/ | M | /tts/ | vot | /tt/ | vot | /ss/ | M./ts/ / M./s/ | ./tts/ / ./ss/ | ./tts/ / M./ts/ | ./ss/ / M./s/ |
| M1 | -,- | - | - | - | - | - | - | - | - | - | - | - | - | - |
| M2 | 112,95 | 103.5 | 26 | 103,12 | 116* | 152 | 38 | 165 | 16 | 223* | 0.89 | 0.68 | 1.46 | 1.92 |
| M3 | 87,93 | 90 | - | 97,137 | 117* | 205 | - | 180 | 26 | 161 | 0.76 | 1.27 | 2.27 | 1.37 |
| M4 | 85,98 | 91.5 | 36.5 | 91,93 | 92* | 174 | 38 | 219 | 12.5 | 162 | 0.99 | 1.07 | 1.90 | 1.76 |
| M5 | -,- | - | - | - | - | - | - | - | - | - | - | - | - | - |
| M6 | 130,142 | 136 | 30 | 142,242 | 192* | - | - | - | - | - | 0.70 | - | - | - |
| M7 | 123,89 | 106 | 46 | 114,123 | 118.5* | 186 | 90 | 169 | 24 | 130 | 0.89 | 1.43 | 1.75 | 1.09 |
| M8 | 115,110 | 112.5 | 30 | 115,137 | 126* | 184 | - | 150 | 32.5 | 164 | 0.89 | 1.12 | 1.63 | 1.30 |
| M9 | 153,- | 153 | 42.5 | 84,102 | 93 | - | - | - | - | - | 1.64 | - | - | - |
| M10 | 171,169 | 170 | 88.5 | 170,168 | 169 | 271 | 56 | 236 | 17 | 256 | 1.00 | 1.05 | 1.59 | 1.51 |
| M11 | 90,- | 90 | 30 | 98,- | 98* | - | - | - | - | - | 0.91 | - | - | - |
| M12 | 104,- | 104 | - | 77,93 | 85 | 157+ | - | 156 | 26 | 152 | 1.22 | 1.03 | 1.50 | 1.78 |
| M13 | 108,120 | 114 | 16 | 146,131 | 138.5* | - | - | - | - | - | 0.82 | - | - | - |
| M14 | 111,97 | 104 | 33 | 132,170 | 151* | 170 | 42 | 161 | 26 | 152 | 0.68 | 1.11 | 1.63 | 1.00 |
| M15 | 108,96 | 102 | 38.5 | 110,119 | 114.5* | 175 | 59 | 195 | 37 | 166 | 0.89 | 1.05 | 1.71 | 1.44 |
| F1 | 119,- | 119 | 23 | 121,117 | 119* | 226 | 65 | 193 | 37 | - | 1.00 | - | 1.89 | - |
| ASP | - | 113.9 | 36.6 | - | 123.5 | 190 | 49.6 | 186 | 25.4 | 174 | 0.92 | 1.09 | 1.66 | 1.40 |

NOTE: * means that non-glottalic stop is either longer than glottalic or equal.
ASP means all speakers pooled together.
M means mean.
\+ means two figures (144,170) averaged.

6.14.4 /k'/ and /k/.

Comparing the glottalic and the non-glottalic single and geminate stops, I found that when durations are averaged across speakers the glottalic stop has the longer mean duration; this was 135.3 msec (N=25) while the non-glottalic stop had mean 114.2 msec (N=27). See Table 6.41. In contrast, the non-glottalic geminate shows longer mean duration than its glottalic counterpart (204.8 msec (N=9) versus 190.3 msec (N=9)). Duration values for the single and geminate stops for each speaker showed that there is considerable variation between speakers. 5 of the 14 speakers (M2, M3, M4, M13 and M15) produced single and geminate non-glottalic stops longer than the corresponding glottalic stop. All speakers (except M7) produced the non-glottalic geminate stop longer than the glottalic geminate stop. However, in the case of M2 glottalic geminate stop was longer than the non-glottalic geminate stop. (cf. Table 6.41). For three out of the nine speakers, the ratio /k'k'/: m(k') is greater than the ratio /kk/: m(k).

Table 6.41: Durations, mean, mean VOT and duration ratios for the velar ejective.

| | Durations and mean durations (in msec) | | | | | | | | | | Ratios | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spk | /k'/ | M | vot | /k/ | M | vot | /k'k'/ | vot | /kk/ | vot | M./k'/ / M./k/ | ./k'k'/ / M./kk/ | ./k'k'/ / M./k'/ | ./kk/ / M./k/ |
| M1 | -,- | - | - | - | - | - | - | - | - | - | - | - | - | - |
| M2 | 94,86 | 90 | - | 103,97 | 100* | 29 | 193 | 17 | 194* | 37.5 | 0.90 | 0.99 | 2.14 | 1.94 |
| M3 | 112,92 | 102 | 34.5 | 108,100 | 104* | 37 | 192 | 63 | 194 | 41 | 0.98 | 0.98 | 1.88 | 1.86 |
| M4 | 90,93 | 91.5 | 25.5 | -,100 | 100* | 23 | 158 | 63 | 208* | 32 | 0.91 | 0.75 | 1.72 | 2.08 |
| M5 | -,- | - | - | -,- | - | - | - | - | - | - | - | - | - | |
| M6 | 294,149 | 221.5 | 74 | 105,102 | 103.5 | 41.5 | - | - | - | - | 2.14 | - | - | - |
| M7 | -,- | - | - | 115,113 | 114 | 34.5 | 141 | 58 | 139 | 51 | - | 1.01 | - | 1.21 |
| M8 | 144,109 | 126.5 | 39 | 117,128 | 122.5 | 46 | 239 | 91 | 242 | 95 | 1.03 | 0.98 | 1.89 | 1.97 |
| M9 | 132,134 | 133 | 51.5 | 92,99 | 95.5 | 35.5 | - | - | - | - | 1.39 | - | - | - |
| M10 | 175,205 | 190 | 95 | 124,140 | 132 | 47.5 | 221 | 86 | 232* | 73 | 1.43 | 0.95 | 1.16 | 1.75 |
| M11 | 120,141 | 130.5 | 52 | 93,120 | 106.5 | 41 | - | - | - | - | 1.22 | - | - | - |
| M12 | 110,- | 110 | 46 | 93,118 | 105.5 | 41 | 166 | 51 | 205* | 55 | 1.04 | 0.80 | 1.50 | 1.94 |
| M13 | 99,116 | 107.5 | 35 | 120,126 | 123* | 36 | - | - | - | - | 0.87 | - | - | - |
| M14 | 131,152 | 141.5 | 52.5 | 134,149 | 141.5* | 52.5 | 185 | 61 | 195* | 56 | 1.00 | 0.94 | 1.30 | 1.37 |
| M15 | 127,88 | 107.5 | 34.5 | 140,120 | 130* | 53 | 218 | 61 | 234* | 52 | 0.82 | 0.93 | 2.02 | 1.80 |
| F1 | 219,196 | 207.5 | 47 | 111,132 | 121.5 | 40 | - | - | - | - | 1.70 | - | - | - |
| ASP | - | 135.3 | 48.8 | - | 114.2 | 39.8 | 190.3 | 61.2 | 204.8 | 54.7 | 1.18 | 0.92 | 1.40 | 1.79 |

NOTE: * means that non-glottalic stop is either longer than glottalic or equal.
ASP means all speakers pooled together.
M means mean.
+ means two figures (144,170) averaged.

6.14.4.1 VOT.

Published research papers dealing with VOT in Hausa are those of Ladefoged (1968), Meyers (1976) and Lindau (1984). The authors measured the VOT of the ejective stops in an intervocalic position. The vowel environment was restricted to /a/ in all tokens, and geminates did not constitute part of the investigation. Their findings are summarized as follows (cf. section 6.3 for relevant literature).

Ladefoged (1968) observed that for his informants, the ejective had an interval of 50-60 msec between the release of the velar closure and the start of the vowel. This, he said, was longer than the period of aspiration following /k/ which usually lasted about 35-45 msec (1968:5). Meyers (1976) reports that /k'/ has an average VOT of 67 msec while /k/ and /t/ have an average of 49 msec and 39 msec each (1976:44). In agreement, my data shows that VOT is longer in both single and geminate glottalic stops, averaging 48.8 msec and 61.2 msec for single and geminate stops respectively, compared to 39.8 msec and 54.7 msec for non-glottalic (cf. Table 6.41).

It is not as yet clear whether the longer duration or the long period of voicelessness following the burst release of the ejective function as an important cue in distinguishing between the glottalic voiceless stop and its non-glottalic counterpart, since I have undertaken no perceptual tests. Further research, including perceptual testing, would be desirable to confirm or reject this hypothesis.

It is interesting to note that Fre Woldu's (1985) study of Tigrinya stops reports that the most important acoustic cue that distinguishes an ejective plus vowel sequence from a voiceless aspirated stop followed by a vowel is the silent period (cf. section 5.6.4). The release and the vowel onset had less value in the rank order of cue strength. I quote,

> "The main conclusion reached regarding, as establishing the rank order of ejective plus vowel acoustic cue is that the silent period of ejective following the burst release is the strongest cue. A period of silence following a burst release is therefore the perceptually essential feature of ejective stops. It is a feature of the acoustic signal demanded by the native Tigrinya listener's social phonetic (linguistic) norm" (Fre Woldu 1985:110).

6.14.5 /'y/, /y/ and /ʔ/.

Comparing the mean closure duration between /'y/ and /ʔ/, the results show that the glottalic palatal glide was longer than the glottal stop for all speakers who recorded the glottal stop. The mean glottal closure duration for /'y/ was 141.7 msec (N=16) compared to 87 msec (N=21) for the glottal stop. See Table 6.42. Also, comparing /'y/ with /y/, the results show that the glottalic palatal glide was longer than its plain counterpart for 10 of the 13 speakers; the mean closure duration for the plain glide was 115.2 msec (N=13) (cf. Table 6.42).

Table 6.42: Durations, mean durations and duration ratios for the laryngealized palatal, plain palatal glide and glottal stop.

| | Durations and mean durations (in msec) | | | | Ratios |
|---|---|---|---|---|---|
| | /'y/ | /y/ | /?/ | mean./?/ | /'y/ / /y/ |
| M1 | 109 | 102 | -,- | - | 1.06 |
| M2 | 102 | 107* | 79,- | 79 | 0.95 |
| M3 | 123 | 87 | 79,106 | 92.5 | 1.41 |
| M4 | 138 | 113 | 79,95 | 87 | 1.22 |
| M5 | 170 | 114 | -,- | - | 1.49 |
| M6 | 189 | 136 | -,- | - | 1.38 |
| M7 | 138 | 123 | 94,124 | 109 | 1.12 |
| M8 | 193 | 102 | 130,111 | 120.5 | 1.89 |
| M9 | 116 | 135* | 47,86 | 66.5 | 0.85 |
| M10 | 141 | 158* | 72,81 | 76.5 | 0.89 |
| M11 | 119 | 95 | -,- | - | 1.25 |
| M12 | 110 | - | 94,98 | 96 | - |
| M13 | 131 | 127 | 91,97 | 94 | 1.03 |
| M14 | 200 | - | 61,83 | 72 | - |
| M15 | 111 | 99 | -,- | - | 1.12 |
| F1 | 178 | - | 38,92 | 65 | - |
| ASP | 141.7 | 115.2 | - | 87 | 1.23 |

### 6.14.6 Summary: Duration Measurements.

Although there is wide variation (due to the reasons mentioned above), the glottalic consonants are generally longer than their plain counterparts. This confirmed the previous observations made by Meyers (1976) that the glottalic consonants are longer than the plain ones. However, in our data the ejectives are once more found to be less differentiated. /k'/ on the average is slightly longer than /k/ and this seems to be attributable to a longer VOT, as was observed by both Ladefoged (1968) and Meyers (1976). To these, the following tentative observations can be added:

1 /ts/ and geminate /k'k'/ tend to be slightly shorter,

than their plain counterparts, but geminate /tts/ is longer;

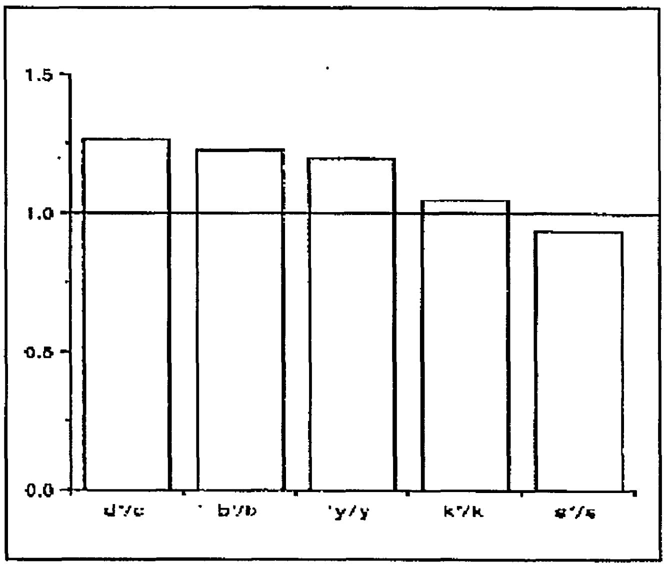
2 the relative duration of the single and geminate stops (both glottalic and plain) shows that the geminates are significantly longer than single stop in the same place of articulation (similar observation was made for Italian single and geminate stops cf. Carminati (1984));

3 single consonants tend to have shorter VOTs than their geminate counterparts; and

4 /'y/ is longer not only than /y/ but also than /?/.

See Fig. 6.67 which shows the ratios of single glottalic to plain consonant duration.

Figure 6.67: Ratios of single glottalic to plain consonant duration.



## 6.15 Summary and Conclusion.

The experiments described in this study were carried with the aim of investigating the phonetic nature of Hausa glottalic consonants in the light of what has previously been said and also to shed light on the growing body of data on these consonants.

We have shown that laryngographic technique can be successfully applied to the investigation of phonation types in a language where they are used contrastively. In particular, laryngographic derived OQ has been shown to be a good parameter for distinguishing consonant type in Hausa. One reason that makes the study interesting is the fact that both OQ and Fo were looked at together. In the literature Fo is usually looked at separately (cf. Hombert et al. (1979)).

As Lindau (1984) suggests there is considerable variability in the realization of phonological categories of consonantal voice quality. Our results show, however, that a degree of consistency within categories can be extracted instrumentally from recordings of different speakers of Hausa producing plain and glottalic consonants.

The main problem which arose in the laryngographic analysis of the glottalic consonants was the occurence in some tokens of irregular voicing with some vibrations of very low amplitude. Although there were grounds for assuming close approximation of the vocal folds, they were algorithmically interpreted as (or, on occasion, could be entirely indistinguishable from) periods of glottal opening. While such cases present a real problem for the automatic implementation of this sort of laryngographic analysis, they can generally be identified with confidence by the phonetician. In any case, the number of tokens involved was relatively small.

We shall now review the results of the experiments:

1 **The nature of /b'/, /d'/, /'y/, and /ʔ/:** At the onset of the laryngealized stops /b'/ and /d'/ the vocal folds come together for one or two long cycles of vocal fold vibration during the first part of the following vowel. /'y/ and /ʔ/ shows a similar pattern. From a qualitative point of view all these segments are not dissimilar as they all involve several vibrations with progressive decrease in OP and increase in CP most of the time. This is not surprising at all since these segments are defined as phonologically the same. Even though sometimes it is quite possible to make a theoretical distinction between the different Lx waveforms (in other words they may be phonetically different), they are all points on a continuum from "long glottal stop" to "a series of creaky cycles". It is interesting to find that the general pattern in the Lx waveform types associated with the laryngealized stops and the palatal glide applies in my data to the glottal stop segment as well.

It is also interesting to see that from the waveforms and to some extent from auditory analysis:

1 the longest cycles occur during the consonant and
2 the effect of some of the glottalic consonants on phonation type is greater at the start than at the end of the consonant.

This is in agreement with Meyer's (1976) observation that the glottal consonants are more clearly distinguished from the plain ones at the start of the consonant than at the end. And it contrasts with the statement of Ladefoged (1975:24) that in the glottalized stops of

"Hausa and many West African languages ... the creaky voice is most evident not during the stop closure itself but during the first part of the following vowel" (although not categorically stated, it seems Ladefoged was talking about perceptual characteristics of the glottalic consonants).

With regard to OQ, the quantitative analysis showed that the laryngealized consonants are more strongly differentiated at the left (C1) than at the right (C2) of the consonant. With regard to Fo movement, the laryngealized consonants are also characterized by a marked drop in Fo at C1. It is suggested that these Fo movements may be important perceptually. Perceptual experiments would therefore be necessary to test this hypothesis.

The question of whether or not /'y/ is produced with a more extreme degree of laryngealization as claimed by Lindau (1984) has been left open. In any case, /'y/, /ʔ/, /b'/ and /d'/ all share low OQ and lowered Fo at the start of the consonantal constriction, which distinguishes them from the other types. The observation here is consistent with the results of our qualitative analysis.

It is very difficult to determine how to interpret these results cross-linguistically, since there is very little study done on the nature of laryngealization (cf. Chapter 5). At this stage all that one can do is to compare with studies based on creaky vowels (cf. Section 5.14 for the list of languages that have contrast between creaky and non-creaky segments). Even in these studies one finds that there are more acoustic studies and these are usually done on the steady portion of the vowel. If we compare Hausa with Hindi in which breathy voice plays a role in distinguishing between consonants, we find that Hausa laryngealized consonants tend to exhibit laryngealization at the onset of occlusion, while in Hindi the action tends to be at the consonant release. For example, Kagaya and Hirose (1975) report that Hindi /bh/ and /dh/ are produced with the glottis mostly closed during the oral closure until it begins to open just before the oral release (See Chapter 5.5.3).

With regards to Fo movements, our results put Hausa with languages in which [ʔ] lowers the Fo of the preceding vowel (cf. Hombert et al. (1979)). This though perhaps unusual, this is consistent with the observed affinity of glottal stop and laryngealization in the language. Some lowering of Fo (relative to the preceding vowel) is observed for all the consonant types.

2 **The Nature of the Ejectives /ts/ and /k'/:** Ladefoged (1968:5) described /ts/ not as an ejective affricate but as an ejective fricative [s'] and cites [t'] as the Katsina dialect variant. Similarly, Meyers (1976) describes /ts/ as an ejective fricative and gives two possible articulatory patterns for the segment:

1 in which the pattern of articulatory timing shows a glottal occlusion which is released with laryngealized voicing during the friction of the /s/, and
2 representing an articulatory pattern where during the friction noise of the /s/ there is no longer a glottal component.

Our recordings of the ejective /ts/ shows silent periods both after the friction and preceding it; this is considered an indication of a genuine affricate.

Glottal closure occurs at consonant onset and this stricture lasts through the full duration of the consonant. In addition the results are interpreted as showing upward movement of the larynx for /ts/ which is not present for /s/. Not all speakers produced /ts/ as a proper ejective affricate as some speakers produced /s/. There is scope for further study including perceptual tests to determine whether this variability involves neutralization of the contrast between /ts/ and /s/. In addition the results could be interpreted as showing upward movement of the larynx for /ts/ particularly at the point where the consonant is released which is not present for /s/.

As in Lindau (1984), /k'/ was not always realized as proper ejective. A minority of the speakers pronounced it as [k], or were inconsistent in the realization of the segment. Further study would be desirable including perceptual tests to determine whether this variability involves neutralization of the contrast between /k'/ and /k/. In addition the results could be interpreted as showing upward movement of the larynx for /k'/ particularly at the point where the consonant is released which is not present for /k/.

In the quantitative analysis, ejectives showed both higher OQ and higher Fo at C1. This is somewhat surprising since a simultaneous glottal stop is necessary for the production of an ejective. However, there is a great deal of variability in the data, and as we noted already marked OQ lowering at C1 is observed for some tokens.Still, these are balanced by other tokens with relatively high OQ at C1. Perhaps the lack of aspiration in /k'/ is sufficient to distinguish it from /k/. Compare the facts of the Korean stop series reported by Abberton (1972:2). She reports that, the female speaker she examined "appears to rely much more heavily on VOT as differentiating feature than the male speaker who also has a characteristic type of voice onset with one series of stops".

3 **The Nature of the Plain Voiceless Consonants, /k/ and /s/:** In contrast to the laryngealized segments the plain voiceless consonants show a higher normalized OQ at C1. They also show distinctively high normalized OQ at C2, and they are also characterized by raised Fo at this environment. The fact that there is higher normalized OQ at the left-hand environment of the consonant (C1) suggests that the glottal opening gesture begins before the oral constriction. The fact that OQ is still high at the right-hand environment of the consonant (C2) suggests that the vocal folds start to vibrate again gradually before the glottis is fully closed. This conclusion is consistent with the results of fiberoptic studies (cf.Section 5.5.3).

As regards VOT, experimental findings on this are few and inconclusive. The only published research dealing with VOT in Hausa are the already mentioned Ladefoged (1968), Meyers (1976) and Lindau (1984) (cf. Section 6.14.4.1). The authors compared the glottalized stops with the non-glottalized ones. The geminates did not constitute part of their investigation. In the present study, VOT of each utterance is measured on the speech waveforms. The results of the voiceless consonants show that VOT of /tt/ (the single counterpart was not recorded) is about 25.4 msec on the average and that of /k/ is about 39.8 msec, while that of /kk/ is about 54.7 msec on the average (cf. Tables 6.40 and 6.41). These results are comparable to those reported by Lisker and Abramson (1964), Vagges et al. (1978) and Carminati (1984).

4 **The Nature of the Plain Voiced Consonants, /b/, /d/ and /y/:** All waveforms show periodic vibrations of the vocal folds throughout the duration of the consonants. As far as these consonants are concerned the mean normalised OQ at C1 and C2 remain at approximately the same value. The fact that OQ remains at approximately the same value suggests that the glottis retains the same degree of closure during the consonants. Again this is consistent with the results of fiberoptic studies obtained on the voiced segments of Hindi. Kagaya and Hirose's (1975) fiberoptic investigation of Hindi stops report that /b/ and /d/ are characterized by a lack of glottal opening all through the articulatory closure period of the consonants.

**The Geminate Consonants.**

5 **The Nature of the Laryngealized Geminate Consonants:** Geminates /b'/ and /d'/ are more consistent in the profile of Lx waveform than the singles, being sufficiently long in duration for a marked glottal closure to occur. This suggests that the target is a true glottal stop but that is only achieved given a long consonantal duration. In the quantitative analysis, we found no significant difference between the singles and the geminates with regard to normalized OQ and Fo movement (cf. Section 6.12.6).

6 **The Ejectives:** No qualitative difference was observed between the geminate ejectives and the single ejective segments /ts/ and /k'/. In the quantitative analysis, it seems that at the left-hand environment (onset of occlusion) of the consonant the geminates show lower values for normalized OQ. The low normalised OQ at C1 for the geminates suggests that the initial glottal closure is (on average) stronger for the geminates

than for the single ejectives. We have suggested that the geminate ejectives are not so subject to "weak" articulation as the single ejectives. It would be desirable to investigate the relationship between the relative timing of the glottal raising and oral closing gestures.

7 **Plain Voiced stops:** The quantitative analysis indicated that plain voiced geminates show lower OQ at the onset of the occlusion and higher OQ at the end of the occlusion than their single counterparts. It is not immediately clear why this should be the case. However, the higher normalized OQ at C2 (which is taken to indicate relatively breathy phonation) is consistent with the suggestion of Halle and Stevens (1967) that breathier phonation must be adopted if voicing is to be maintained.

8 **Plain Voiceless Consonants:** The quantitative analysis indicated that the plain voiceless geminates showed less OQ raising at the consonant onset than their single counterparts. We have suggested that this may be explained with reference to relative timing of oral closing gestures (cf. section 6.12.6).

**Duration.**

As mentioned in section 6.14 no definitive statement can be made in this thesis as regards consonant duration due to the reasons mentioned in section 6.14.1. However, we are able to draw some general differences between the segments.

9 The glottalic consonants are generally longer than their non-glottalic counterparts confirming previous observation made by Meyers (1976).

10 The ejective /k'/ is on average slightly longer than /k/ and this seems to be attributable to a longer VOT, as was observed by Ladefoged (1968) and Meyers (1976).

11 /ts/ and geminate /k'k'/ tend to be slightly shorter than their plain counterparts, but the geminate /tts/ is longer.

12 The relative duration of the single and geminate stops (both glottalic and non-glottalic) shows that the geminates are significantly longer than single stops in the same place of articulation. Although there are few studies aimed at determining experimentally the acoustic correlates of consonant length, they have not been entirely consistent in the measures taken. However, similar observation was made for Italian single and geminate stops cf. Carminati (1984); for Bengali and Turkish cf. Lahiri et al. (1988) and for geminate and non-geminate in Arabic cf. Obrecht (1965).

13 In agreement with previous studies (Ladefoged (1968) and Meyers (1976)), my data shows that VOT is longer in both single and geminate ejective stops, averaging 48.8 msec and 61.2 msec for the single and geminate stops respectively, compared to 39.8 msec and 54.7 msec for the plain stops. Perceptual tests would be desirable to confirm whether the duration of the VOT serves as an important cue in distinguishing the ejectives from plain stops.

14 Single consonants tend to have shorter VOTs than their geminate counterparts. With regard to the possible relationship between VOT and closure duration, experimental findings on this are scanty and inconclusive. Kent and Moll (1969) found no

correlation between VOT and closure duration, while Umeda and Coker (1974) noted a positive correlation between the two. However, because both these studies were of American English and did not encounter closure durations of more than 150-200 msec, they are of limited relevance to our case, as Hausa geminates can have closure periods as long as 230 msec. More relevant and thorough is the investigation by Carminati (1984) into closure duration and aspiration in Italian. Although Italian does not have any phonemic opposition between glottalic and non-glottalic stops, the author found that voiceless geminates tend to have slightly shorter VOTs than their single counterparts.

15 /'y/ is longer not only than /y/ but also than /?/.

Before concluding, it should be mentioned that word-initial consonants have not been considered in this thesis, and are left for future study. A combined laryngographic and spectrographic study of all the consonants investigated would have helped to provide more detailed and accurate phonetic description of Hausa glottalic consonants, had time permitted.

## 6.16 Notes.

1 I am grateful to Dr. E. Abberton, Dr. David M. Howard, Dr. Geoffrey Lindsey, Dr. Mark Huckvale, Mr. Steve Nevard and Mr. Andrew Breen for helping me take decisions on particular categories of Lx and Sp waveforms.

2 It is hoped that most of the interpretations of the different labels offered here will find a measure of agreement with my readers' interpretations.

# Appendices and References

**APPENDIX 1**

I was fortunate to be able to visit the Ferens Institute of Otolaryngology at the Middlesex Hospital London for fibreoptic examination on two occasions.

The fibrescope used was the Pentax naso-endoscope (model FS 10), which was coupled with an ELMO 102 miniature video camera. During the sessions, the image was displayed on a video monitor and recorded on U-matic video tape. Surface anaesthesia (of the mucous membrane of the nose and pharyngeal wall) and insertion of the scope were performed by Mr. D Garfield Davies in the first session and by Mr. R. Dhillon in the second.

During both sessions, I read the list of Hausa words used in the laryngographic study. In the first session, both single consonants and geminates were recorded, while only single consonants were recorded in the second. This material was not ideal because, as will be remembered, the consonants were preceded and followed by /a/ rather than /i/. The view of the larynx was often blocked by retraction of the root of the tongue and the epiglottis. Because filming was at normal speed, it was possible to observe only gross movements.

The tape which is now kept in the Department of Phonetics and Linguistics at SOAS, was viewed several times following the sessions. In addition, some individual frames were printed using a Mitsubishi P50B video recorder, which produces monochrome displays on specially treated paper. These prints were made in the Phonetics Laboratory, University of Oxford.

The material was not suitable for quantitative study, but some qualitative observations can be made. During the production of the laryngealized consonants, including /ʔ/ and /'y/, the arytenoids are tilted forward and are pulled forward towards the thyroid cartilage; in extreme examples the view of the folds may be blocked completely. In contrast, during the plain consonants more of the vocal folds is visible. See Figures A.1. and A.2. which show the variation of the laryngeal gestures during the production of /'y/ in the word /**'yaa'yaa**/ = 'children'; /y/ in the word /**yàayàa**/ = 'how'; /d'd'/ in the word /**d'ad'd'àfaa**/ = 'to accuse someone falsely' and /dd/ in the word /**daddà faa**/ = 'to cook many times'.

Simultaneous laryngographic recordings were not made. However, it is of interest that, in the laryngographic study, my Lx waveform shows a particularly long closed phase, longer than in an English "creak". For the entire length of the consonant sometimes only one or two long cycles of vocal fold vibration occur indicating a very long glottal closure (cf. Fig. 6.28(a). In the quantitative analysis, my OQ values for the laryngealized consonants were very low (38.50).

At the end of the first session, the endoscope was pulled out a bit so that the lower pharynx could be observed. It was found that some pharyngeal constriction accompanied the laryngealized consonants as well.

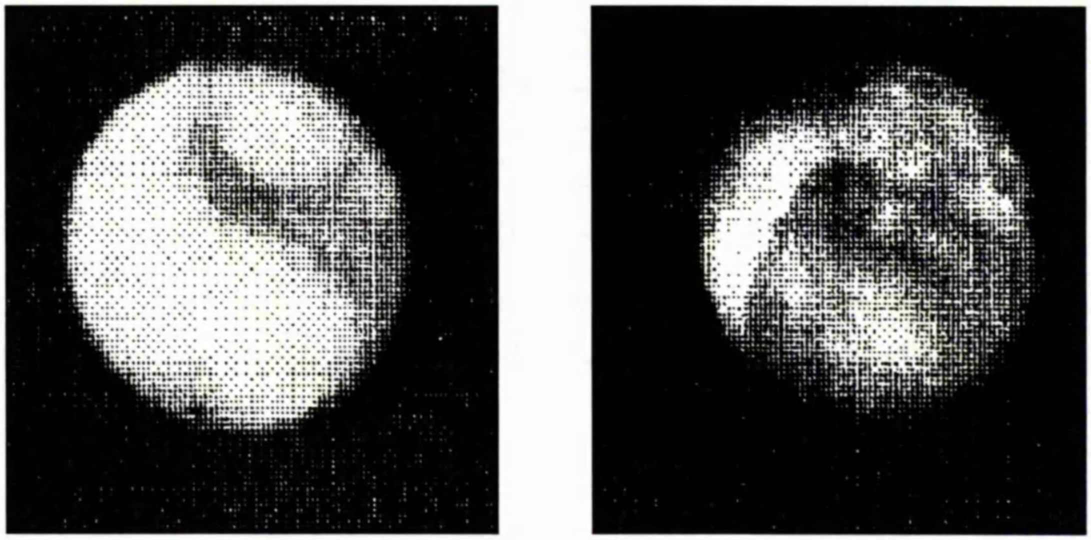


Figure A.1: Photographs of the larynx during glottalized and non-glottalized palatal glide produced by speaker M7 (a) /**'yaa'yaa**/ = 'children' and (b) /**yàayàa**/ = 'how'.

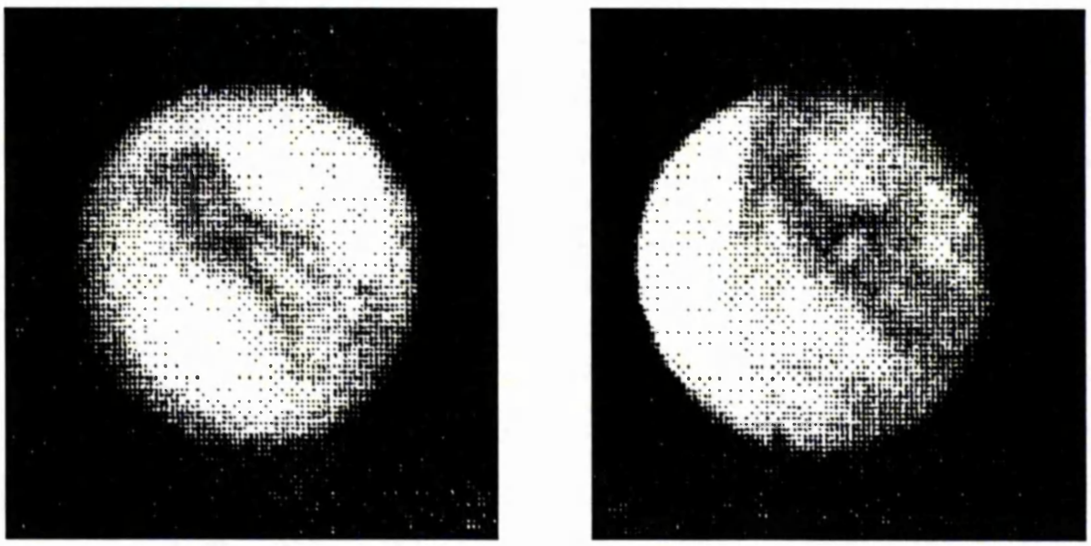
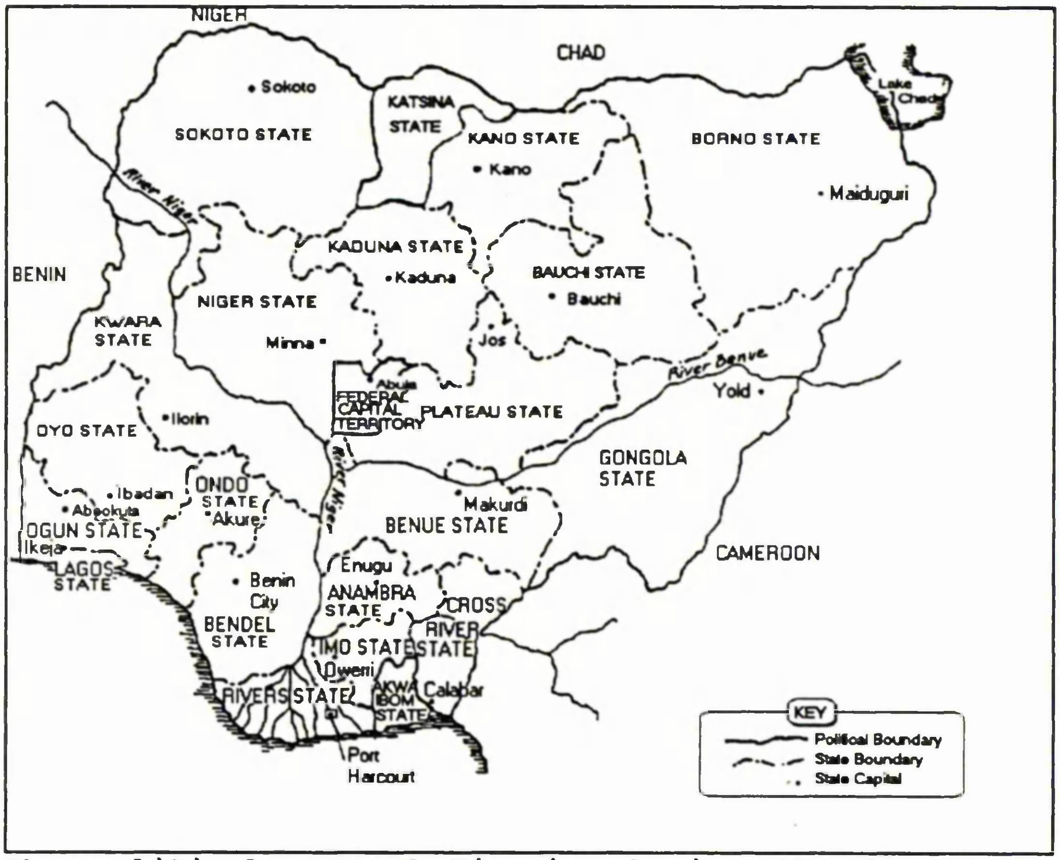


Figure A.2: Photographs of the larynx during glottalized and non-glottalized geminate alveolar stops produced by speaker M7 (a) /**d'ad'd'àfaa**/ = 'to accuse someone falsely' and (b) /**daddà.faa**/ = 'to cook many times'.

APPENDIX 2




The political map of Nigeria showing the twenty-one states.
Source: West Africa, 5.10.87 p1953.

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