AN EXPERIMENTAL STUDY OF VOWEL DURATION IN IRAQI SPOKEN ARABIC

ZEKI MAJEED HASSAN
(AL-JAZARY)

Thesis submitted in fulfilment of the requirements for the Degree of Ph.D.

University of Leeds
Department of Linguistics and Phonetics
June, 1981

TO MY WIFE

CONTENTS

Page

Page

Page

ABSTRACT

This is an experimental study of vowel duration in I.S.A. (Iraqi Spoken Arabic). It investigates some myodynamic (articulatory), aerodynamic, acoustic and perceptual correlates of vowel duration and aims at answering, partly at least, the question whether the factors governing the systematic variations of vowel duration are phonetic-universal or language-specific phenomena. It falls into two main parts:

PART ONE comprises three chapters. Chapter One gives a general phonological background of I.S.A. with special reference to the phonemic significance of vowel length and its correlation with stress. Chapter Two reviews some of the literature on vowel duration. The literature review is confined to a critical survey of particular aspects of vowel duration viz; intrinsic duration of vowels, segmental conditioning of vowel duration i.e. the influence of voicing and manner of articulation of the preceding and following consonants and the place of articulation of the following consonants on vowel duration, the influence of stress and gemination on vowel duration and some of the literature on the perception of duration. Chapter Three reviews critically some of the hypotheses for the interpretation of vowel duration in myodynamic (articulatory) and aerodynamic terms. The hypotheses reviewed are articulatory distance, force of

articulation and articulatory energy expenditure, contrasting aerodynamic conditions, laryngeal adjustment, temporal compensation and closure transition.

PART TWO comprises three chapters giving details of the experimental investigation and discussion of results. The intention has been to keep in line with the same aspects of vowel duration reviewed in Part One; the same aspects have been investigated from the acoustic point of view in Chapter Four. The acoustic findings have been subjected to a myodynamic and aerodynamic investigation in Chapter Five. The results of both chapters have been subjected to statistical treatment. In Chapter Six the findings of both Chapter Four and Five are summarized and discussed from the myodynamic, aerodynamic, acoustic and perceptual points of view. Suggestions for further research have also been included at the end of this chapter.

ACKNOWLEDGEMENTS

I should like to express my appreciation and thanks to all the people who have contributed, in one way or another, to the achievement of this thesis.

My most sincere gratitude is due to Mrs C. Scully and Mr D. Barber who have shared the supervision of this research. I am very much indebted to their consistent and efficient guidance, encouragement, friendliness and their invaluable suggestions and comments.

My thanks are also due to Mr E. Brearley who was a constant source of help and advice while I was carrying out my experiments in the laboratory.

My thanks are also extended to Mr Howes of the Department of Psychology for his suggestions concerning the statistical treatment of the data.

I wish to thank Dr. P. Roach for his excellent comments on the laryngographic analysis of the data and for kindly putting the computer facilities at my disposal.

I also acknowledge the efforts of Mr H. Al-Roubaii of the Department of Mechanical Engineering in bringing the figures and illustrations of this thesis to their final version.

Thanks are also due to the departmental secretaries for their kindness and assistance with administrative arrangements, and to Mrs Val Grant for her efforts in typing the thesis.

Special gratitude and appreciation are due to my wife for her patience, understanding and support all through the years of this research.

Last but not least, my thanks are extended to the Ministry of Education for providing me with the Study Leave without which this research could not have been achieved.

ZEKI MAJEED HASSAN

LIST OF ABBREVIATIONS AND SYMBOLS

A	It represents area in the orifice equation $u = K.A. \sqrt{\Delta P}$, and used alternately with Ac.
Ac	Area of constriction
Ac. min.	Minimum cross-sectional Area of Constriction
Av.	Average
C.A.	Classical Arabic
ch.	channel
cm/s	centimeter/second
dB	decibel
Dup. Osc.	Duplex Oscillogram
Dur.	Duration
Fo	Fundamental Frequency
F_1	First Formant
F_2	Second Formant
F.J.	Frøkjær-Jensen
H.P.	High Pass
Int.	Intensity
I.S.A.	Iraqi Spoken Arabic
Hz	Hertz
K	Constant
KHz	Kilo Hertz
L/m	litre/minute

msec	milliseconds
mingo	Mingograph
mm/s	millimeter/second
P	It represents pressure in the orifice equation $u = K.A. \sqrt{\Delta P}$ and used alternately with Po.
Po	Intra oral air pressure
p	probability
ΔP	Pressure drop across the tongue constriction
U	U values of Mann Whitney U test.
u	It represents airflow in the orifice equation $u = K.A. \sqrt{\Delta P}$ and used alternately with Uo.
Uo	Volume Flow Rate of Air Through the Mouth
UCL	University College of London
V.Fs	Vocal Folds
vs	versus
$>$	more than
$<$	less than
$\leq$	equal to or less than
/ /	Phonemic transcription
†	The reader is referred to the statistical note on page 200a.

LIST OF TABLES AND FIGURES

TRANSCRIPTION

The segmental symbols used in this study have been selected to fulfil two main objectives; firstly, to facilitate the reading of the transcribed examples and hence they represent phonemic rather than phonetic values. Secondly, to give the reader a general account of the phonological classification of consonants and vowels in Iraqi spoken Arabic (hereafter I.S.A.). A phonetic diagram is also included here to show the approximate tongue positions for the vowel phonemes of I.S.A. and some of their allophones. The reader will be referred to this diagram later in this study whenever the discussion of vowel quantity necessitates reference to vowel quality.

1. CONSONANTS

(a) Plosives

/p/ a voiceless bilabial plosive e.g. /'parda/ "curtain", /'puuʃi / "veil"

/b/ a voiced bilabial plosive e.g. /baat/ "spent the night", /biir/ "a well".

/$\underline{b}$/ a voiced bilabial emphatic plosive e.g. /'$\underline{b}$a$\underline{b}$a/ "daddy", /$\underline{t}$u$\underline{b}$/ "enter" (imp. sing.)

/t/ a voiceless denti-alveolar plosive e.g. /tiin/ "fig", /toom/ "twin".

/ṯ/ a voiceless denti-alveolar emphatic plosive e.g. /ṯiin/ "clay", /ṯaar/ "flew" (sing.)

/d/ a voiced denti-alveolar plosive e.g. /diin/ "religion", /dam/ "blood".

/ḏ/ a voiced denti-alveolar emphatic plosive e.g. /ḏeem/ "misery", /ḏeef/ "visitor"[1]

/k/ a voiceless velar plosive e.g. /ki'faaħ/ "struggle" /'kaafi/ "enough".

/g/ a voiced velar plosive e.g. /gaam/ "stood up", /gaal/ "said".

/q/ a voiceless uvular plosive e.g. /'qalam/ "pencil", /'qadam/ "foot".

/ʔ/ a glottal stop e.g. /'ʔamal/ "hope" , /'ʔadab/ "literature".

(b) Fricatives

/f/ a voiceless labio-dental fricative e.g. /faat/ "passed by", /faar/ "rat"[2]

---

(1) It is usually replaced by /ð̱/ by both educated and non-educated Iraqi speakers and it is only retained by some Christian Communities.

(2) /f̱/ is considered as an emphatic variant of /f/.

/θ/ a voiceless interdental fricative e.g. /θuum/ "garlic", /'θawra/ "revolution".

/ð/ a voiced interdental fricative e.g. /'ðakar/ "male" /ðeel/ "tail"

/ð̲/ a voiced interdental emphatic fricative e.g. /'ð̲ulum/ "tyranny", /'ð̲alma/ "dark".

/s/ a voiceless denti-alveolar fricative e.g. /sa'laam/ "peace", /'saami/ "proper name".

/s̲/ a voiceless denti-alveolar emphatic fricative e.g. /baas̲/ "bus", /s̲eed/ "hunting".

/z/ a voiced denti-alveolar fricative e.g. /zaad/ "food", /faaz/ "won".

/ʃ/ a voiceless palato-alveolar fricative, e.g. /ʕaaʃ/ "lived", /ʃaaf/ "saw".

/x/ a voiceless uvular fricative e.g. /xad/ "cheek", /xoof/ "fear".

/ɣ/ a voiced uvular fricative e.g. /'ɣabi/ "stupid", /'ɣada/ "lunch".

/ħ/ a voiceless pharyngeal fricative e.g. /'ħarub/ "war", /raaħ/ "went away".

/ʕ/ a voiced pharyngeal fricative e.g. /ʕaad/ "came back", /baaʕ/ "sold".

/h/ a glottal fricative e.g. /'haadi/ "proper name", /'fahad/ "leopard".

(c) Nasals

/m/ a voiced bilabial nasal e.g. /maat/ "died", /naam/ "slept".

/n/ a voiced denti-alveolar nasal e.g. /naar/ "fire", /xaan/ "betrayed". also 'store-house'.

(d) Affricates

/tʃ/ a voiceless palato-alveolar affricate e.g. /tʃaaj/ "tea", /tʃi'biːr/ "big, large".

/dʒ/ a voiced palato-alveolar affricate e.g. /dʒaaf/ "dry", /'dʒisir/ "bridge".

(e) Approximants

/l/ A voiced alveolar lateral approximant e.g. /laam/ "reproached", /naal/ "won".

/l̠/ a voiced alveolar lateral emphatic approximant /'xaal̠i/ "my uncle", /'gal̠l̠a/ "fried". vs. /'galla/ "he told them".

/w/ a voiced labio-velar approximant e.g. /'waadi/ "valley", /waħid/ "one".

/j/ a voiced palatal approximant e.g. /joom/ "a day", /'jidri/ "he knows".

(f) Flap

/r/ a voiced alveolar flap e.g. /raad/ "he wanted", /'baarid/ "cold".(1)

/r̲/ a voiced alveolar emphatic flap e.g. /r̲af̲/ "shelf".

2. VOWELS

(a) Phonetic Description

/ii/ a long close front unrounded vowel e.g. /diin/ "religion".

/i/ a short close to half close front unrounded vowel e.g. /sin/ "tooth".

/ee/ a long half close to half open front unrounded vowel e.g. /zeet/ "oil".

/a/ a short half open to open front unrounded vowel e.g. /bas/ "enough".

/aa/ a long open front unrounded vowel e.g. /baas/ "kissed".

/oo/ a long half close to half open back rounded vowel e.g. /noom/ "sleeping".

/u/ a short close to half close back rounded vowel e.g. /fuk/ "open".

---

(1) It is trilled when geminated e.g. /'ħarrar/ "liberated".

/uu/ a long close back rounded vowel e.g. /buus/ "kiss" (imp.)

(b) Allophonic Variation

Vowels of I.S.A. have wide ranges of allophonic variations as shown in the phonetic diagram below. The allophonic variation we are mostly concerned with in this study is that brought about by the adjacent pharyngeal and emphatic versus front consonants. Front vowels are lowered and either centralized or backed when preceded and/or followed by pharyngeal and emphatic consonants. Back vowels are also lowered and backed when preceded and/or followed by pharyngeal and emphatic consonants, on the one hand, and, on the other hand, they are slightly centralized when they are preceded and/or followed by front consonants.

As examples of the above facts, the most phonetically distinct allophones are indicated on the phonetic diagram and represented by numbers in order not to cause confusion in the reading of phonemic transcriptions. Examples are given below for each of these allophones.

/ii/ 1. e.g. /tiin/ "fig". 2. e.g. /$\underline{t}$iin/ "clay"

/i/ 1. e.g. /sin/ "tooth". 2. e.g. /$\underline{t}$ib/ "medicine"

/ee/ 1. e.g. /zeet/ "oil". 2. e.g. /$\underline{t}$eer/ "bird"

/a/ 1. e.g. /bas/ "enough". 2. e.g. /ʕad/ "calculated"

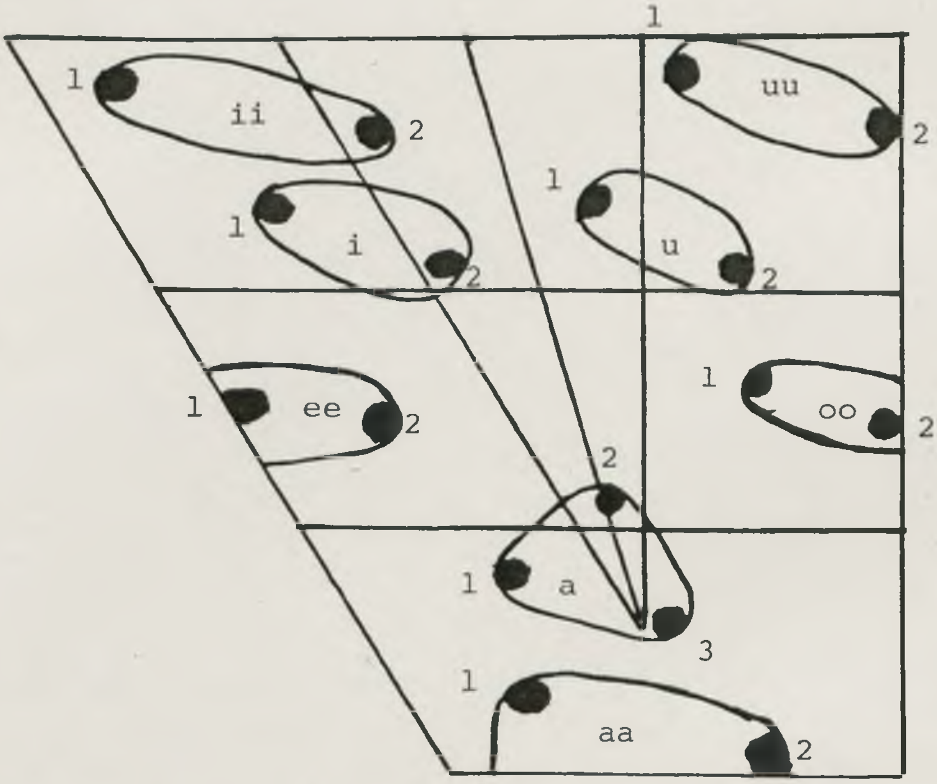
3. e.g. /bas/ "peeped".

/aa/ 1. e.g. /saas/ "foundation" 2. e.g. /saas/ "sauce"

/oo/ 1. e.g. /boos/ "kissing". 2. e.g. /soot/ "sound" (n.)

/u/ 1. e.g. /fuk/ "open". (v.) 2. e.g. /bus/ "peep" imp.
Never used in I.S.A.

/uu/ 1. e.g. /buus/ "kiss". (v.) 2. e.g. /tuus/ "containers"



Phonetic diagram showing approximate tongue positions for the vowel phonemes of I.S.A. and some of their allophones.

INTRODUCTION

Previous studies on the systematic variations of vowel duration have revealed some aspects of the organization of speech production processes, the acoustic structure of speech sounds and how both interact with perception to bring about the speech segments heard as linguistic units. Physical measurements of articulatory and acoustic events correlated with their perceptual realization have shown in recent years that there are law-governed regularities in the timing of speech. Such regularities may give the linguist an insight into various phonetic-universal and language-specific phenomena underlying human speech communication.

In consequence, the reader will find that this study is, in the main, a phonetic study of vowel duration in Iraqi Spoken Arabic (hereafter I.S.A.) based on experimental investigation.

Many questions arose as to how we could conduct a reliable investigation on some acoustic aspects of vowel duration in I.S.A. These questions concern the precision of our experimental methods, the instruments used, the dialect investigated, the reliability of our segmentation criteria and measurements and the overall assessment of the results obtained and the conclusions derived.

The dialect selected for this investigation is that commonly used by almost all educated Iraqi speakers which is often termed Baghdadi Arabic (Odisho 1973). Being the dialect of the capital Baghdad, it has the greatest privilege of spreading and being more popular than the other local dialects in the country which are related to the unchanged system of Classical Arabic (hereafter C.A.). The phonological background of I.S.A. and its relation with C.A. is found in Chapter One. However, to be more precise in the assessment of my dialect, since I have acted as the subject of the experiments involved and originally come from Basrah in the south of Iraq, one should consider two important facts; (a) it may reflect some idiosyncratic and dialectal features peculiar to my own speech, (b) it may contain some vocabulary that may appear alien to some Iraqi speakers in the other parts of the country. Apart from that my dialect is, on the whole, affiliated with the commonly spoken dialect, understandable in all parts of the country which I have termed I.S.A.

The study falls into two parts. The first part gives a general phonological background of I.S.A. with special reference to the phonemic significance of vowel length and its correlation with the phenomenon of stress. It also reviews some of the vast literature on vowel duration. The literature review has been confined to certain aspects i.e. intrinsic duration of vowels, segmental conditioning of vowel duration, the influence of stress and gemination on vowel duration and some of the literature on the perception of duration. It also reviews some of the hypotheses for the interpretation of vowel duration in myodynamic and aerodynamic terms.

In Part Two the same aspects of vowel duration, reviewed in Part One, have been investigated from the acoustic point of view in Chapter Four. The acoustic results have, then, been subjected to a myodynamic (articulatory) and aerodynamic investigation in Chapter Five. In Chapter Six the results of both investigations have been summarized and discussed from the myodynamic, aerodynamic, acoustic and perceptual points of view.

Although this study is, in the main, a phonetic study, as has been specified earlier, it is to be emphasized that the acoustic and articulatory aspects investigated are studied within the framework of the phonology of I.S.A. That is, the phonological system of contrasts pervades the whole of the data, because the contexts investigated are within that framework of contrasts. This may emphasize the fact that the phonetic data give an insight into the phonological implications and it would be unwise to separate phonetics from phonology and linguistics. Lehiste (1970, p.vi) states:

> 'For a linguist, phonetics is only a means towards an end, not a purpose in itself. The end is to provide reliable answers to linguistically relevant questions.'

Nevertheless, Lehiste also believes that phonetics is still indispensible in providing these answers and that a phonologist ignores phonetics at his own peril.

Certain problems also arose in determining whether differences of vowel length are more distinctive when they are accompanied by simultaneous differences of vowel quality as it is the case with I.S.A. vowels. A phonetic analysis treating of vowel quality from the articulatory acoustic and perceptual points of view, which is not available in the literature so far, could have added another element in the enhancement of our conclusions on the durational differences between long and short vowels in I.S.A. Among the future aims of the author is to investigate vowel quality on the above mentioned levels and relate them to the findings of this study to complete the whole picture.

Finally, we hope that this study may have clarified, partly at least, some of the questions continuously raised on the intrinsic and the extrinsic factors that govern the acoustic variations of vowel duration and their perceptual and phonological implications.

P A R T   O N E

PHONOLOGICAL BACKGROUND AND SURVEY OF LITERATURE

CHAPTER ONE

PHONOLOGICAL BACKGROUND

1.1 Duration and Length

Every speech sound has physical and perceptual attributes. The perceptual values of any speech sound are related to the physically measurable values that can be studied more objectively. For the purpose of this study duration is defined as a physical attribute representing the measurable duration of a speech sound from the articulatory and acoustic points of view. Lehiste (1970) states that the duration of a speech sound represents the time dimension of the acoustical signal and defines it as, 'the physical correlate of the timing of the articulatory sequences.' (op. cit., p.9). On the other hand, length is defined as a perceptual attribute that contributes to the perception of a speech sound. In consequence, vowel duration will be used here as a phonetic term referring to the acoustic and articulatory aspects and used alternately, later in this study, with the term vocoid duration,(1) whereas vowel length will be

---

(1) See section 4.1 for definitions of vocoids and contoids.

used here as a phonological term referring to the perceptual or psychoacoustic aspects that may or may not lead to phonological opposition. However, in our survey of the literature on vowel duration the two terms vowel duration and vowel length are sometimes used synonymously because no such distinction has been attempted by some of the writers concerned. Similarly, no such distinction is made when we discuss or comment on the points or hypotheses raised by these authors even when the perceptual and phonological implications of vowel duration are tackled.

1.2 The Phonological Significance of Vowel Length in C.A. and I.S.A.

The vowel system of C.A. has often been described as a triangular system comprising three long vowels /ii/, /aa/ and /uu/ and their short counterparts /i/, /a/ and /u/ (Ferguson (1957), Al-Ani (1970) and (1978)). Similar classification of I.S.A. vowels has also been suggested; the vowel system of I.S.A. comprises eight vowel phonemes; five long vowels /ii/, /ee/, /aa/, /oo/ and /uu/, and three short vowels /i/, /a/ and /u/ (Odisho (1973), Ghalib (1977)). Ferguson (1957) and Erwin (1963) also suggest the vowel phoneme /o/ as a short counterpart of /oo/ which is not included in this study as it is only rarely observed in some loan words and could be very well considered as a variant of /u/.

The question naturally arises in this context whether the quantitative difference between long and short vowels in C.A. and I.S.A. is accompanied by an equally noticeable qualitative difference. Al-Ani (1970) found that the long vowels of C.A. are twice the length of their short counterparts, and, therefore, considers vowel length as phonemically distinctive and that long vowels should be represented by doubling the same symbol. On the other hand, his cineradiographic and spectrographic data showed very little difference in phonetic quality between /ii/ and /i/, and /uu/ and /u/ whereas /aa/ and /a/ were found to be discernably different; the tongue position with /aa/ seemed lower and somewhat more retracted than with /a/.(1) It is unfortunate that no such investigation has yet been made for I.S.A. vowels and the identification of their phonetic quality remains intuitive and dependent, in the main, on articulatory and auditory judgements. However,

---

(1) The adjacent consonants selected were non-emphatic.

there seems to be unanimous agreement among the linguists who have touched on this point that, like Al-Ani's findings in C.A., there is a slight simultaneous qualitative difference accompanying the very considerable observable length difference between the long vowels /ii/, /aa/ and /uu/ and their short counterparts /i/, /a/ and /u/.

Nevertheless, it seems difficult to determine whether the listener responds to either the quality difference or quantity difference or both equally to distinguish phonologically between long and short vowels. However, it seems plausible to think that the listener uses both as concomitant cues for phonological distinction though it appears that vowel length is a more efficient cue since the vowel length difference is more extreme than that of vowel quality. This can only be feasibly determined when perceptual tests are made for which both quality and length are controlled in order to see whether the listener responds mainly to one or other of them. This is unfortunately not available in the literature so far.

1.3 Syllabic Structure in C.A. and I.S.A.

1.3.1 General Background

We believe that any synchronic study of I.S.A. should be primarily based on the diachronic data of C.A. as it has always been regarded as the standard or the norm to which I.S.A. and all the other Arabic dialects refer. This includes the phonological, morphological, grammatical and lexical aspects of the language. It is true that I.S.A. has undergone some modifications under the influence of Turkish and Persian but these modifications are so insignificant that they have not affected the basic linguistic principles that still operate in both C.A. and I.S.A.

Arabic is an inflected language i.e., the grammatical relationships can be shown by inflection as well as word order. The root or the base in Arabic is of three consonants and it carries no lexical information unless it is integrated with the infixes which are composed of one vowel or more to form the stem which is the basic unit that carries lexical information e.g. the root k-t-b becomes /'katab/ "wrote" after adding the infix a-a. The vowel (infix) distribution in the root of the word changes variably, leading to other changes in grammar and meaning e.g. /ki'taab/ "a book", /'kutub/ "books", /'kaatib/ "writer" ... etc. Further grammatical and semantic changes may be brought about by the addition of affixes (prefixes and suffixes) and the word may have one or more prefixes and/or suffixes e.g. /ki'taaba/ "writing", /kitaa'baat/ "writings", /kitaa'baatuhu/ "his writings", /'ʔaktubu/ "I write", /sa'ʔaktubu/ "I shall write" ... etc.[1]

The isolate word in C.A. is used in either pausal or non-pausal form. The pausal forms involve the omission of final inflectional /a, i, u, un and in/, and the use of common ending /ah/ to correspond to non-pausal /-atun/, /-atan/ and /-atin/ e.g.

/'katab/ "wrote" (pausal) versus /'kataba/[2] (non-pausal)
/'jaktub/ "write (pausal) versus /'jaktubu/ (non-pausal)
/'kaatib/ "writer" (pausal) versus /'kaatibun/ (non-pausal)
/'kaatiba/ "female writer" (pausal) versus /'kaatibatun/ (non-pausal)[3]

Although the same principles of word structure of C.A. also operate in I.S.A. many modifications affect

---

(1) For more details of word structure in Arabic see Al-Ani (1978).
(2) The segmental symbols used in this study for I.S.A. can also apply for C.A.
(3) For more details of pausal and non-pausal forms in C.A. see Mitchell (1960).

the stem, prefixes and suffixes; and the phonetic value of some consonantal and vocalic segments are quite distinct in I.S.A. Besides, no distinction is made between pausal and non-pausal forms no matter whether the word is isolate or within discourse.

Examples:

C.A. Pausal	C.A. Non-pausal	I.S.A.	Meaning
/'katab/	/'kataba/	/'kitab/	"wrote"
/qaal/	/'qaala/	/gaal/	"he said"
/qult/	/'qultu/	/'gilit/	"I said"
/ka'biir/	/ka'biirun/	/tʃi'biir/	"big"
/daw2/	/'daw2un/	/'ðuwa/	"light"
/ki'taabuh/	/ki'taabuhu/	/ki'taaba/	"his book"
/2aʕ'taak/	/2aʕ'taaka/	/2in'taak/	"He gave you"

1.3.2. Syllabic Structure in C.A.

The following are the basic rules that operate in the phonological system in C.A. without exception:

1. The syllabic nuclei is always composed of a vowel either long or short and no syllabic consonant has been reported to exist that may function like English /n/ in [bʌtn̩]. Consequently, the

number of vowels in any utterance is equal to the number of syllables and, therefore, the number of syllables in an utterance is easily and automatically defined.

2. No syllable and, therefore, no utterance begins with a vowel but only with CV sequences.

3. The vowel can be preceded by only one consonant and followed by no consonant, one consonant or two consonants and hence syllables in Arabic can be either open or closed.

In the light of the above rules the following are all the possible forms of C.A. syllable:

1. CV(1) as in /bi/ "in, at", /wa/ "and"
2. CVV as in /fii/ "in", /maa/ "what"
3. CVC as in /min/ "from", /sin/ "tooth"
4. CVCC as in /dars/ "lesson", /fadʒr/ "dawn"
5. CVVC as in /ðaab/ "melted", /baab/ "door"
6. CVVCC as in /maarr/ "passer by" /maass/ "one that touches"

---

(1) C stands for single consonants.
V stands for short vowels.
VV stands for long vowels.
CC stands either for consonant clusters or for geminate consonants.

The first type is called a short open syllable. The second type is a medium open syllable; note that when it occurs immediately before any syllable beginning with /hamzatal-wasl/ (the assimilatory glottal stop), it is realized as type three e.g. /fii-al-kitaab/ becomes /fil-kitaab/. The third type is called a medium closed syllable. Types 4, 5 and 6 are called long closed syllables. The first three syllables comprise the majority of non-lexical (grammatical) words. Most lexical words with pausal endings may come in the form of types 2, 3, 4, 5 and 6.

So far as frequency of occurrence is concerned the first three syllables are the most frequent ones. Frequency of occurrence decreases from CVCC, CVVC and CVVCC respectively. The first three syllable types may occur in an utterance initially, medially and finally. The other three types rarely occur in non-final positions and the last one is restricted to final position only.

The word in C.A. may consist of one type of the preceding six types or up to three types as in /juriiduun/. Also, it may consist of up to seven syllables whatever affixes it may have. Words of six and seven syllables, however, are relatively rare.

Examples:

one syllable /min/ "from"

two syllables /ˈʕaalim/ "scientist" (pausal)

three syllables /ˈjuʕallim/ "he teaches" (pausal)

four syllables /juʕalli'muun/ "they teach" (pausal)

five syllables /juʕalli'muuna/ "they teach (non-pausal)

six syllables /juʕalli'muunahu/ "they teach him" (non-pausal)

seven syllables /sajuʕalli'muunahu/ "they will teach him"(non-pausal) (1)

1.3.3 Syllabic Structure in I.S.A.

Besides the modifications occurring in I.S.A. that differ from the standard or the norm, i.e. the classical form mentioned in 1.3.1, the following tendencies could also be detected in the syllabic structure of I.S.A. that differ from the syllabic structure of C.A.

1. There is a tendency to elide a short unstressed vowel between the initial and medial consonants in C.A. bisyllabic words, merging the first and second syllables into one syllable, e.g.

C.A.	I.S.A.	Meaning
/kit'taab/	/ktaab/	"a book"

(1) For more details of syllabic structure in C.A. see Mitchell (1960), Anis (1971) and Al-Ani (1978).

C.A.	I.S.A.	Meaning
/ħa'miir/	/ħmiir/	"donkeys"
/ba'ʕiir/	/bʕiir/	"camel"

2. Iraqi Arabic speakers also tend to reduce the number of syllables in C.A. words having three syllables or more, e.g.

C.A.	I.S.A.	Meaning
/'katabat/	/'kitbat/	"she wrote"
/'ʔiftaħuu/	/'fitħuu/	"open" (imp.plur.)
/ka'tabna/	/'kitban/	"they wrote" (fem. plur.)

3. There is a tendency to insert a short vowel between the two final consonants cluster of C.A. syllables type CVCC making it type CVC (the whole word becoming CVCVC) e.g.

C.A.	I.S.A.	Meaning
/faqr/	/fuqur/ or fugur/	"poverty"
/bakr/	/'bakir/	"proper name"
/ɣadr/	/'ɣadir/	"betrayal"

4. When the two initial consonants cluster of I.S.A. syllable type CCVV or CCVVC are both plosives voiceless and/or voiced, there is a

tendency to add an epenthetic short vowel at the beginning of the syllable making it of the sequence VCCVV or VCCVVC as in /ktaab/ which is actually pronounced [^{i}ktaab]. This [i] is phonologically redundant and in rapid discourse it is usually elided after a final vowel of a preceding word as in /'ʕindi k'taab/ "I have a book".

5. There are more syllable types other than the six possible types of C.A. syllable that exist in I.S.A. The following are all the possible types of I.S.A. syllable:

    1. CV as in /la/ "not"
    2. CVV as in /loo/ "if"
    3. CVC as in /bas/ "enough"
    4. CVVC as in /baab/ "door"
    5. CVCC as in /fard/ "individual"
    6. CVVCC as in /maarr/ "passer by"
    7. CCVV as in /ʃfaa/ "cured him"
    8. CCVVC as in /ktaab/ "a book"
    9. CCVCC as in /ʃbint/ "dillweed"

1.4 Stress and Vowel Length

1.4.1 Correlates of Stress

No attempt has been made in this study to give a specific definition for the phenomenon of stress as all the definitions found so far in the literature have failed to exhaust all the physiological, acoustic, psychoacoustic and phonological correlates of this extremely complex phenomenon. Nevertheless, we will take as a basis the definition suggested by Jassem (1959) which is specifically starting from the phonological implications of this phenomenon:

> 'Stress is a phonologically relevant or relevant set of mutually exclusive and complementary features of a syllable which marks the syllable as "stressed" (if present) or "unstressed" (if absent) in the morphological and syntactic system of the language' (op. cit., p.254).

Jassem (op. cit., p.254) also suggests the following sets of correlates for the phenomenon of stress categorized in three stages of the speech chain viz.; articulatory, acoustic and psychoacoustic or perceptual stages. He states:

> 'Four features of the speech wave can be distinguished from the phonologic point of view: (a) intensity, (b) energy-frequency distribution (the spectrum),

(c) frequency of the fundamental component, and (d) duration of specified segments of the wave. Their psychoacoustic correlates are: (a) loudness, (b) quality, (c) pitch, (d) subjective duration of specified segments of the sound impression. In the articulatory aspect the corresponding features are: (a) muscular effort, (b) articulation of the supraglottal organs and type of glottal articulation, (c) frequency of the vocal-cord vibration and (d) timing of the supra-glottal articulation and the glottal "quality" articulation.'

However, Jassem also addes that: '... there are interdependencies between some of the features and some of the correlates are not sufficiently well-known.' (ibid).

For the purpose of this study two correlates are considered in some detail; vowel duration as an acoustic correlate of stress in relation to intensity and fundamental frequency,[(1)] and vowel length as a phonological correlate contributing to the perceptual realization of stress.

---

(1) For more details of vowel duration as an acoustic correlate of stress see section 2.4.1.

1.4.2 Vowel Length as a Phonological Correlate of Stress

Vowel length or perceived vowel duration has often been associated with phonological stress on the word level; for several languages it has been demonstrated that vowel length is an efficient cue in the perceptual realization of word stress and that in many languages stressed syllables are invariably heard as longer than unstressed syllables. O'Connor (1973, p.198) states: 'As we listen, the relative lengths of syllables are a further help to the identification of stress'. Trubetzkoy (1969) believes that stress could be realized by: 'lengthening or more precise or more emphatic articulation of the vowels or the consonants involved.' (op. cit., p.188). Ladefoged (1975, p.97) states that: 'the most reliable thing for a listener to detect is that a stressed syllable frequently has a longer vowel.'

In some languages stress and syllable quantity are interrelated. For instance according to the stress patterns of C.A. and I.S.A., as we shall see in the following sections, long vowels and hence long syllables carry stress more than short vowels and syllables, and syllables having long vowels are almost always stressed. On the other hand, unstressed short vowels and unstressed or secondarily stressed long vowels suffer shortening in C.A. Furthermore, unstressed short vowels are sometimes completely elided in I.S.A. and short unstressed syllables are merged with stressed long syllables having long vowels.

1.5 Stress Patterns in Arabic

1.5.1 General Background

The synchronic description of stress patterns in I.S.A. or any other Arabic dialect will be insufficient and unsatisfactory without reference to the diachronic data of C.A., as they all bear close relation to the same syllabic pattern which can be traced back to the unchanged system of the classical, as has been shown in section 1.3.1. Birkeland (1954) believes that the comparative studies of stress patterns in the dialects of Egypt, Syria, Palestine and Iraq, which he considers as the most important dialects outside Arabia proper, revealed that 'their common pattern of stress can be applied to the classical and on that basis all dialectal forms can be explained'. (op. cit., p.7). Mitchell (1960, p.369) states:

> '... not only that rules of prominence are statable for a given colloquial but also that correspondence between colloquials

> or between a colloquial and a given "classical" pronunciation is equally regular.'

There is, however, a controversy about the history of stress in C.A. and how it developed in the dialects and there is no generally accepted theory in this respect. The view put forward by Birkeland (op. cit., p.36) is that:

> 'The fixed word-stress used in most parts of the Arab world and by European scholars when reading Classical Arabic is secondarily introduced into the language from the colloquial, in which purely phonetic and occasional stress gradually developed from a speech phenomenon into a language phenomenon stabilized in fixed relation to quantity.

Mitchell (op. cit., p.369) generally accepts the view that the form or forms of Arabic familiar to the old Arab grammarians 'were not characterized by prominence', and justifies that by calling these grammarians orthoepists concerned mainly with the phonetic powers of the Arabic letters.

Nevertheless, the failure of the old Arab grammarians to mention any phenomenon which could be identified with stress bears testimony to the fact that stress in C.A. has no morphological or semantic function and consequently has no phonemic significance; a fact which all the European and Arab linguists seem to agree on.

Some of these linguists, on the other hand, assume, though this is still controversial, that some dialects have tendencies toward a new system in which stress has phonemic significance which may be, 'due to secondary developments within the respective dialects'. (Birkeland op. cit., p.8). In Cairene Arabic, Harrell (1957) regards stress as having phonemic significance in minimal pairs like /'sikit/ "he was silent" and /si'kit/ "I was silent" or "you were silent" (masc. sing.) and objects to the practice of writing double final letters e.g. /si'kitt/. This view is completely rejected by Mitchell (op. cit., p.375, footnote 2) who states that the second /t/ must be considered, from the morphological point of view, as a suffix that indicates first person or second person singular and thus this example coincides with his rule viz., if the ultimate syllable is long the prominance is oxytonic, as we shall see in the following section.

Ferguson (1957) cites an example in Iraqi Arabic and Damascus Arabic where stress could have phonemic significance after eliding the pronominal suffix of [-h] in words like /xal'laah/ "he let him". He states:

> 'In IrAr and DamAr the -h suffix has disappeared completely. A form like xall$\bar{a}$ "he let him" differs from the form xalla[1] "he let" in having a longer final vowel and in having stress on the last syllable instead of the first.'
> (op. cit., p.472).

Different types and levels of stress have also been reported to exist in some Arabic dialects. Ghalib (1977) recognizes two types of stress patterns in colloquial Iraqi Arabic; one is determined by the syllabic structure of the word and the other by certain grammatical conditions. He believes that both word stress and sentence stress as well as primary and secondary stress exist in the same dialect. Nasr (1960) states that three levels of stress could be recognized in Lebanese Arabic; primary, secondary and tertiary.

1.5.2 Predictability of Stress in C.A.

In so far as the predictability of word-stress

---

(1) Ferguson's transcriptions

in C.A. is concerned, the linguists who have touched on this subject seem to agree, to a great extent, on specific rules applicable in most parts of the Arab world.

Birkeland (1954, p.9) summarizes these rules as follows:

'1. When the final length of a syllable is not counted the stress falls upon the last long syllable of the word.

2. If a word contains no long syllable the first syllable is stressed.

3. The final syllable is stressed when it ends in two consonants, or a geminated consonant, or is closed and contains a long vowel.'

These rules seem to agree largely with the rules set up by Mitchell (op. cit., p.373) based on the pronunciation of C.A. taught in Egyptian Centres which he summarizes in a 7-term system of patterns. He uses the following notation and abbreviations;

/.../ Means, in respect of pre-ultimate syllables, that the syllable so represented is immaterial.

(L) Long ultimate syllable i.e. CVVC or CVCC

(L̲) Not-long ultimate syllable i.e. CV or CVV or CVC

(S) Short syllable i.e. CV

(S̲) Not short syllable i.e. CVV or CVC or CVVC or CVCC.

Pause which is regarded as equivalent to (S̲) in pre-ultimate places to achieve thereby a unified exposition, i.e. to avoid the subdivision of forms in accordance with the number of their constituent syllables.

	Prominence	Examples
1. /.../.../.../.../.../ L	oxytonic	d̲a'rabt, ʔaʕ'maal[1] ... etc
2. /.../.../.../.../S̲/L̲	paroxytonic	mus'taʃfaa, mu'ʕallim ... etc
3. /.../.../.../S̲/S/L̲ (S̲ or #)	paroxytonic	kaa'taba, qaat'talt ... etc
4. /.../.../S̲/S/S/L̲ (S̲ or #)	proparoxytonic	ʔin'kasara, ʔid̲'t̲araba ... etc
5. /.../S̲/S/S/S/L̲ (S̲ or #)	paroxytonic	ʔadwija'tuhu, maʕrifa'tuhu ... etc
6. /S̲/S/S/S/S/L̲ (S̲ or #)	proparoxytonic	ʔadwija'tuhumaa, maʕrifa'tuhumaa .etc
7. /S/S/S/S/S/L̲	paroxytonic	ʃadʒaratu'humaa baqaratu'humaa ..etc

---

(1) Mitchell's transcriptions have been modified to match our convention.

Nevertheless, in so far as it concerns the stability of word-stress in C.A. as spoken and read in the Arab world today, no one seems to give a reasonable account of the variation in the respective patterns from one country to another or from one speaker to another. Blanc (1953, p.120) states:

> 'From a few years listening to Arab radio stations, I gather that no speaker of "correct" classical uses these rules as more than a rough approximation, and that stress patterns vary with locality.'

This may suggest that in order to set up more reliable rules of word-stress in C.A., as well as in any other Arab dialect, phrasal and sentence structure must also be considered, i.e. besides the phonological and morphological structures, the syntactic structures should also be taken into account. Ferguson (1956, p.387) states:

> 'Every consideration of Arabic word-stress which does not take phrasal stress patterns into account is bound to be incomplete and misleading.'

1.5.3 Stress Patterns in I.S.A.

This study is by no means the place for a detailed and meticulous analysis of stress phenomena in I.S.A. However, for the purpose of this study and for the sake of an objective and fruitful approach, the discussion will be confined to the following:

1. The relation between stress and long quantity and to what extent vowel length stands as a determining factor in the phonological realization of stress.

2. The implication of a possible influence of stressed syllables on the deletion of some unstressed syllables which exist in C.A. but disappear in I.S.A. This will also account for the shortening or elision of some short vowels when they are unstressed.

3. The probability that stress has phonemic significance in minimal pair words having sequences of stressed versus unstressed syllables.

The following definitions will serve as a guide for our discussion:

1. Syllables in I.S.A. will be classed as follows:

   (a) short open syllables ⟶ CV
   (b) short closed syllables ⟶ CVC
   (c) long open syllables ⟶ CVV, CCVV
   (d) long closed syllables ⟶ CVCC, CVVC, CVVCC, CCVC, CCVVC, CCVCC.

2. Both primary stress /'C/ and secondary stress /ˌC/ are detectable in I.S.A. as well as in C.A. For the purpose of this discussion, a primary stressed syllable refers to the most prominent syllable in a word having more than one syllable.

   A secondarily stressed syllable refers to the relatively less prominant syllable which is nevertheless more prominant than the other syllables which are considered unstressed.

In accordance with the above statements and definitions, and from listening to educated Iraqi speakers the following rules and notes could be made as regards word-stress patterns in I.S.A.

1. If stressed in a sentence, monosyllabic words always take a primary stress no matter whther the syllable is long or short, e.g. all the monosyllabic words of the carrier sentence used in our experimental investigation are primarily stressed.[1]

2. In bisyllabic and polysyllabic words, the last long syllable (closed or open) in a word takes the primary stress. If it is preceded by another

---

(1) For more details of the carrier sentence and selection of material, see section 4.2.1.

long syllable this preceding long syllable takes a secondary stress, e.g.

/fa'qiir/ "poor"

/'qaatil/ "killer"

/ma'ʕaarif/ "relatives"

/ħa'maama/ "pigeon"

/ħamaa'maat/ "pigeons"

/ħa,maa'maata/ "his pigeons"

3. There are, however, some exceptions to this rule. The exception which we are mostly concerned with here is that associated with some final unstressed long open syllables. In words like /'ʃirbuu/ "drink" (imp. plur.) and /'ʃirbii/ "drink" (imp. fem.) the vowels of the final syllables are represented in the orthography by long vowels; /waw al- dʒa'maaʕa/ indicating plurality and /jaʔ al- taʔniiθ) indicating femininity respectively. However, the long vowels here could be auditorily distinguished as shorter than stressed /uu/ and /ii/ and slightly longer than unstressed /u/ and /i/. This is due to the fact that the primary stress is located on the first rather than on the second syllable. On the other hand, in words like /ʃir'buu/ "drink it" (imp. plur.) (< ʃir'buu + h) and /ʃir'bii/

"drink it" (imp. fem. sing.) (< ʃirbii + h), where a final pronominal /-h/ is completely dropped by Iraqi speakers, the stress shifts from the first to the second syllable rendering the final pronominal /-h/ phonologically redundant and the long vowels /uu/ and /ii/ as perceptually longer than those in /'ʃirbuu/ and /'ʃirbii/. In consequence, stress here stands as the only distinctive feature that could lead to a difference in meaning and is, therefore, phonemically significant. This is compatible with the view expressed by Ferguson (1957) quoted on p.24 in that the phonemic contrast between these words is intimately connected with stress. Further discussion of this phenomenon will be made in section 6.5.3.

The following examples could also be cited to show that the shift of primary stress from the first to the second syllable in some I.S.A. bisyllabic words corresponds to a difference in meaning:

/'salħuu/ "repair" versus /sal'ħuu/ "repair it" (imp. plur.)

/'ʃiftuu/ "you saw" versus /ʃif'tuu/ "you saw him" (imp. plur.)

/'kitbii/ "write" versus /kit'bii/ "write it" (imp. fem.)

/'dʒii,bii/ "bring" versus /,dʒii'bii/ "bring it" (imp.fem.)
/'raaf,qii/ "accompany" versus /,raaf'qii/ "accompany him" (imp. fem.)

4. Short syllables closed or open (i.e. having short vowels and single final consonants) may have primary stress in bisyllabic and polysyllabic words which contain no long syllables e.g.

/'sabab/ "reason"
/'bahðala/ "mess"

5. One could observe that long syllables and long vowels in C.A. are very well preserved in I.S.A. i.e. they have not undergone any significant changes in their quantity as they almost always carry either primary or secondary stress whereas some unstressed short syllables and hence unstressed short vowels are seriously affected i.e. the short vowels are either extremely shortened when adjacent to stressed long syllables or completely elided causing unstressed short syllable to be merged with the long stressed syllable. e.g.

C.A.	I.S.A.	Meaning
/ki'taab/"pausal"	either /k^{i}'taab/ or /ktaab/	"book"
/ħa'miir/"pausal"	either /ħ^{a}'miir/ or /ħmiir/	"donkeys"
/ba,saa'tiin/ "pausal"	either /b^{a},saa'tiin/ or /b,saa'tiin/	"orchards"
/s̱a,waa'riix/ "pausal"	either /s̱^{a},waa'riix/ or /s̱,waa'riix/	"rockets"

This observation could be another indication of the close relation between stress and long quantity in the sense that, had the short vowels been always stressed in C.A., they would never have undergone such extreme reduction in their quantity in I.S.A., as the stressed short syllables and vowels in C.A. never undergo such modification to their quantity in I.S.A.

This greatly supports the view that stress has a powerful effect on the syllabic quantity. Short unstressed syllables and vowels in both C.A. and I.S.A. are heard as discernably shorter than stressed short syllables and vowels. Similarly, secondarily stressed long syllables and long vowels are heard as shorter than primarily stressed long syllables and long vowels. If the long vowel is unstressed, which is rare as it appears from the phonological system of both dialects, it also undergoes considerable shortening as in the examples cited earlier; the long vowels in /'ʃirbuu/ and /'ʃirbii/ are heard as noticeably shorter than the corresponding stressed long vowels in /ʃir'buu/ and /ʃir'bii/.

It also appears from the preceding rules and notes that vowel length is a good manifestation of phonological stress and this combination of stress and long quantity (long syllables and long vowels) is a part of the phonological system of both dialects.

CHAPTER TWO

VOWEL DURATION

A GENERAL SURVEY OF LITERATURE

2.1 Introduction

This chapter is devoted to a survey of some of the literature on vowel duration. The aim has been to focus on the acoustic and perceptual aspects of vowel duration but, inevitably, reference is often made to the myodynamic or articulatory and physiological aspects as well, as some of the writers concerned seem to regard all these aspects as inseparable phonetic aspects of vowel duration. However, the myodynamic (articulatory) and aerodynamic aspects of vowel duration will be dealt with in more detail, in Chapter Three where various hypotheses for interpreting the acoustic variations of vowel duration will be discussed.

In consequence, and for the purpose of this study, the literature survey of this chapter will be confined to the following problems that have been extensively studied by many phoneticians and in different languages:

1. The intrinsic duration of vowels.
2. Segmental conditioning of vowel duration which will include:

(a) The influence of voicing and manner of articulation of the preceding and following consonants on vowel duration.

(b) The influence of the place of articulation of the following consonants as well as that of the vowel itself on vowel duration.

4. The correlation between stress and vowel.

5. The influence of gemination on vowel duration.

The survey will also include discussion of some problems associated with the perception of duration and, in particular, the different threshold values of perception or what has often been termed the just noticeable differences (JNDs) or difference limens (DLs).

For the examples given in this survey the transcriptions will be those of the writers concerned.

2.2 Intrinsic Duration of Vowels

Vowel duration is affected by two main types of phonetic conditioning factors. Lehiste (1970) calls them: intrinsic conditioning factors and segmental conditioning factors i.e. besides the influence exerted by the preceding and following consonants on the duration of a specific vowel, the phonetic quality of a vowel also plays a certain role in determining that duration. Lehiste (op. cit., p.18) uses the term intrinsic vowel duration to refer to the duration of a vowel as determined by its phonetic quality and she states:

> 'As far as the vowels are concerned, their duration appears to be correlated with tongue height; other factors being equal a high vowel is shorter than a low vowel.'

She also believes that:

> 'It is quite probable that the differences in vowel length according to degree of opening are physiologically conditioned and thus constitute a phonetic universal.' (op. cit., pp. 18-19).

In a study on the secondary characteristics of vowels House & Fairbanks (1953) constructed stimulus material by selecting six vowels viz., [i], [e], [ɑ], [a], [o] and [u] which 'span the range of tongue, mandible, and lip position' (op. cit., p.106). These vowels were combined with twelve consonants viz., [p], [b], [t], [d], [k], [g], [f], [v], [s], [z], [m], [n], resulting in a mixed list of words and nonsense syllables, creating bisyllabic nonsense items with iambic stress pattern, [ha] was selected as the appropriate initial syllable, 'since its component sounds are easily pronounced, usually neutral and likely to have minimal effect upon adjacent sounds.' (ibid). The resulting items were 72 words in sequences like "hupeep", "hukak", "hudeed" ... etc.

Ten male students served as subjects. The average age was 20 years and six months, the individuals ranged from 18 years and seven months to 26 years and six months. Those subjects were without speech disorders and had no history of speech pathology and spoke some form of general American English. The procedure involved recording of the subjects' responses to the stimulus items and the 72 items were randomized anew for each subject. On the problems of segmentation they state:

> 'The identification of the beginning and end of a vowel surrounded by consonants is an arbitrary act that is both difficult and artificial. Location of these points was aided by the relative clarity with which they are shown in sound spectrograms.' (op.cit., p.107)

So far as the intrinsic duration of vowels is concerned their results indicate, as shown in the table below, that:

> '... the duration of vowels is directly related to size of mouth opening and inversely related to tongue height. The conformity of [e] and [o] to the progression is interesting since they are commonly diphthongized.' (op.cit., p.111).

They also state:

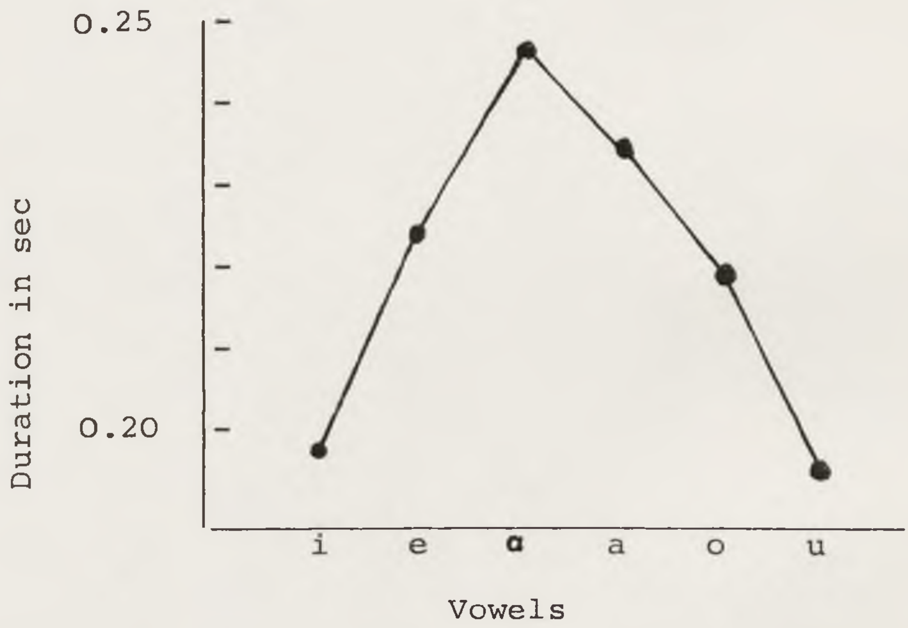
> 'That durational variation should progress as shown is plausible, and probably may be explained on grounds of varying extent of articulatory movement with corresponding varying time.' (ibid). See Table 2.1 and Figure 2.1.

Table (2.1)* Duration means in sec of the six vowels when all the consonant environments are pooled.

	[i]	[e]	[ɑ]	[a]	[o]	[u]
All environments	0.199	0.225	0.244	0.236	0.221	0.195

* After House & Fairbanks (1953).

Fig. (2.1)* Mean duration of vowels when all consonant environments are pooled



* After House & Fairbanks (1953)

House (1961) set out to examine the durational variations between long vowels in American English which he calls "tense" and their short counterparts "lax" vowels, and the durational variations between close vowels and open vowels. The question tackled in this paper is whether these variations are due to the physiological process that produces them and consequently are inherent in this process or whether these variations are part of the language and are learned by persons who used this signalling system.

His speech materials consisted of bisyllabic nonsense words of three adult males. Each nonsense word consisted of an unstressed (carrier) syllable [hə] followed by a stressed syllable having the form $consonant_1$ - vowel - $consonant_2$, where C_1 and C_2 represent the same phoneme. The twelve common vowels of American English and the fourteen consonants that typically appear both initially and finally in American English syllables were used with the vowels. Nasals were avoided because they have no voiceless cognates in English. The speech materials were recorded and the recordings were used in making reference sound spectrograms. The criteria for determining the segment boundaries were the same as those suggested by Peterson & Lehiste (1960)[1]. Frication was included within the formant structure representative of the initiation and termination of voicing whereas aspiration is not included as a part of the vocalic element. The measurements, therefore, as he states:

> 'represent information pertinent to changes in source excitation during syllable articulation, but do not necessarily reveal the point at which a so-called vowel articulation per se began or ended.' (op.cit., p.1174)

---

(1) For more details of the segmentation criteria suggested by Peterson & Lehiste (1960), see section 4.2.5.1.

In the discussion of his results he rejects an overall explanation in terms of the physiological process. His data have shown that:

> '... the average duration of vowels increases with so-called vocalic tenseness and with vocalic openness.' (op. cit., p.1177).

He then adds, to make the comparison more specific:

> 'Tenseness, however, is a descriptive phonetic term that correlates with closeness when contrasting pairs such as[i], [I], [u] [ʊ] ... etc., are compared.' (ibid).

House (op. cit.) believes that the explanation of the durational variation between a long close "tense" vowel and its short "lax" counterpart should not be given in the same terms as explanations of the durational variations between high (close) vowels and low (open) vowels because the two influences associated with vowel articulation itself as he put it:

> '... are not explicable in the same terms since vowel duration increases as tongue height increases in one case and as tongue height decreases in the other.' (ibid)

On the basis of this assumption, House (op. cit.) advances the hypothesis that lengthening found in "tense" vowels is a part of the phonology of the language and that lengthening found in open vowels is a function of the articulatory process itself. He specifies the general inherent influences on vowel duration as the manner of production of consonant context and the open - close dimension of vowel articulation. (Other things being equal).

In complement to the discussion started by House (op. cit.), Delattre (1962) puts forward eight factors of vowel duration in American English apart from stress and tempo:

> 'Three "internal" factors that are in the vowel itself, and five "external" factors all to be found in the single consonant that follows the vowel.'
> (op. cit., p.1141).

The three internal factors[1] are specified as: (1) vowel abridging/vowel expanding, (2) less open vowel/more open vowel, (3) monophthong/diphthong.

Delattre (op. cit.) generally agrees with House (op. cit.) that the overall explanation in terms of a physiological process is untenable and that [i]/[I]

---

(1) For more details of the five external factors see section (2.3).

difference of length where longer/shorter correlates with closer/opener cannot be explained in the same articulatory terms as for example [e]/[i] difference of length where longer/shorter correlates, on the contrary, with opener/closer. However, he strongly objects to the terms lax vowels/tense vowels and replaces them by the terms vowel abridging/vowel expanding respectively.

Lindblom (1968) is also concerned with the same problem; whether to consider the acoustic facts of vowel duration as linguistically determined or as sequences of universal physiological conditions on human speech production. On this basis he set out to analyse Swedish open and close vowels in terms of their production to find out whether, besides tongue height, mandible position is also involved in this process. He states:

> 'Since the inherent duration of a vowel has been associated with its tongue height, and tongue height and jaw opening appear to be correlated in non-compensatory modes of pronunciation, it is natural to expect at least an approximate correlation also between vowel duration and mandible position.' (op. cit., p.2).

He constructed a dynamic model of lip and mandible coordination that gives an articulatory interpretation of the dependence of vowel duration on jaw position. In this model the lip and the mandible are represented by damped spring-mass systems in a way that permits the derivation of the course of the midsagittal separation of the lips. These predictions of the observed durational difference (close versus open vowels) shown by the model were tested against data of lip and jaw movement collected by the following procedure; the lip and the jaw were recorded continuously and in synchrony with the speech signal. Miniature cylindrical lamps were attached to the speakers' lips and to a special device indicating the position of the mandible. Measurements were made of the vertical movements of lamps on the lips and the jaw device which were aligned midsagittally. Three subjects were asked to sustain Swedish vowels (long and short) by reading lists consisting of randomized sequences of nonsense words in an [Ib - b(b)I] frame e.g. [lba:bI], [lbi:bI] .. etc. For each speaker the duration of each vowel segment was defined as the interval between the plosion of the first [b] and the initiation of the occlusion for the second [b]. The results of these measurements were pooled and averaged.

In discussing his results, he reaches three conclusions:

'1. Evidence from the articulatory modelling as well as from experimental measurements makes it appear likely that it is the dynamic behaviour of the mandible that gives rise to the dependence of acoustic vowel duration on the degree of vowel opening.

2. The universality of this dependence is thus contingent upon the extent to which the timing and rate of mandible movement observed in the present investigation for Swedish are typical also of other languages.

3. The results suggest also that the motor control of open and close vowel duration may be characterized by less durational variability than their acoustic representations.' (op. cit., p.24).

With reference to the argument started by House (op. cit.) and in particular whether the durational difference between long "tense" vowels and their short "lax" counterparts is a part of the phonology of the language and learned by the speaker or physiologically conditioned, Condax and Krones (1976) set out to test the following hypothesis:

"... if the mechanical constraints of the vocal tract were removed from speech production, then only those differences in vowel duration which are linguisticially significant from the point of view of the speaker (i.e. differences which are programmed in the brain, and learned as part of language) would be found to be significant.' (op.cit., p.256).

A technique was developed to allow subjects to control the durations of selected syllables using a switch connected to a computer-driven speech synthesizer. This procedure necessarily eliminated any contribution to durational variations which could be attributed solely to the mechanical constraints of the vocal tract. Any significant differences found could be assumed to reflect durational differences programmed in the brain. The vocal tract was replaced by a switch operated by the subjects which was connected to a computer-driven speech synthesizer programmed to deliver combinations of sibilant and vowel to make the four test words [sis] "cease", [sɪs] "sis", [sæs] "sass" [sɔs] "sauce".

Their results showed that the durations of all four vowels [i, ɪ, æ, ɔ] were significantly different in normal speech; in manually produced synthetic speech in general only [I] was significantly different from the joint mean value of [i,æ,ɔ] (significantly shorter). On the other hand, differences between the durations of [i,æ,ɔ] were not significant. This suggested that the latter durations are peripherally determined.

To be more specific; under experimental conditions the results showed that it is the relatively large difference between the two "tense" vowels [i,æ] that disappears and the relatively small difference between the members of a "tense"/"lax" [i,I] pair that remains significant. In consequence, their ultimate conclusion is that:

> '... only the difference between the "tense" vowel and its corresponding "lax" vowel is learned and programmed as part of language production by the speaker." (op. cit., p.263).

Summary

It appears from the foregoing arguments that in languages where the durational difference between long and short vowels is clear cut and phonologically significant, it is most likely that the process of lengthening the long vowel to make it appear significantly different from its corresponding short vowel is made deliberately by the speaker and not physiologically conditioned. In consequence, it is a language specific phenomenon determined by the phonological system of the language and, therefore, linguistically significant from the point of view of the speaker and the listener simultaneously.

On the other hand, the durational variations found between open and close vowels are determined by mandible position and degrees of tongue height and are, therefore, inherent characteristics of vowel duration which are physiologically conditioned. Consequently, it is not linguistically significant form the point of view of the speaker, though it may be perceptually distinguished by the hearer. From the investigations made so far on this phenomenon in several languages, these durational differences may constitute a phonetic universal phenomenon.

2.3 Segmental Conditioning of Vowel Duration

What we mean by segmental conditioning of vowel duration is the influence exerted by the preceding and/or following consonants on the duration of a vowel. This influence varies according to voicing, manner of articulation and place of articulation of the preceding and/or the following consonant. This type of influence has been extensively studied by many phoneticians and in several languages. Most of these studies have been made on the basis of acoustic and articulatory analysis, though from the phonological point of view, some linguists predicted long ago some durational variations of vowels according to the following consonant. It has been known among English linguists, for instance, that the duration of a vowel is usually shorter when followed by a voiceless (fortis) consonant than when it is followed by a voiced (lenis) consonant (Jones (1950) and (1976), Gimson (1970)).

Delattre (1962) specifies the factors that affect vowel duration and besides the three internal factors that are related directly to the vowel itself[1] (apart from stress and tempo), he mentions five external factors all to be found in the single consonant that follows the vowel. These external factors are:

'(C1) surd consonant/sonant consonant
(C2) stop consonant/fricative consonant
(C3) liquid consonant/solid consonant
(all except r and l), (C4) oral stop
consonant/nasal stop consonant
(C5) more front consonant/more back
consonant (within each of the six
categories, surd stops, surd fricatives,

---

(1)See Section 2.2 for the three internal factors.

> sonant oral stops, sonant nasal stops, sonant fricative, liquids.)' (op. cit., p.1141).

2.3.1 Voicing and Manner of Articulation

Voicing and manner of articulation of the following consonant have been considered by many phoneticians as having the greatest influence on vowel duration. In their classic study of the influence of consonants on vowels House & Fairbanks (1953), reviewed in section 2.2, found that in American English vowel duration varies significantly in sequences of vowels followed by voiced versus voiceless consonants:

> 'All voiced environments, furthermore, produced vowels that differed significantly from all those produced in voiceless environments.' (op. cit., p.108).

When all responses are pooled with respect to this characteristic as shown in table (2.2) there is a statistically significant difference of 0.079 sec between the two means. In consequence, they put forward the assumption that:

> '... the voicing of a vowel in a voiceless environment, in contrast to a voiced environment, is withheld until the physiological vowel "target" is

more nearly approximated, and terminated
sooner in the transition to the
following consonant.' (ibid).

As for manner of articulation, the results showed that the values for vowels surrounded by stop, fricative and nasal consonants vary over a 0.036 sec range, and demonstrate means that differ significantly. Concerning voiced consonants having different manner of articulation the results shown in figure (2.2) indicate the trend for fricative sounds to prolong vowels more than do stop plosives. They assume that this is largely due to the fact that:

'... the gradual, controlled movements
of continuants favour longer vowel
duration more than the abrupt, ballistic
movements of the stop plosives.' (ibid).

Onthe whole, their results showed that vowels become longer in this order:

voiced fricatives [vz] > voiced stop [bdg] (where the [consonant] means vowel before the consonant and > indicates longer than), nasals [mn] > voiceless fricatives [fs] > voiceless stops [ptk].

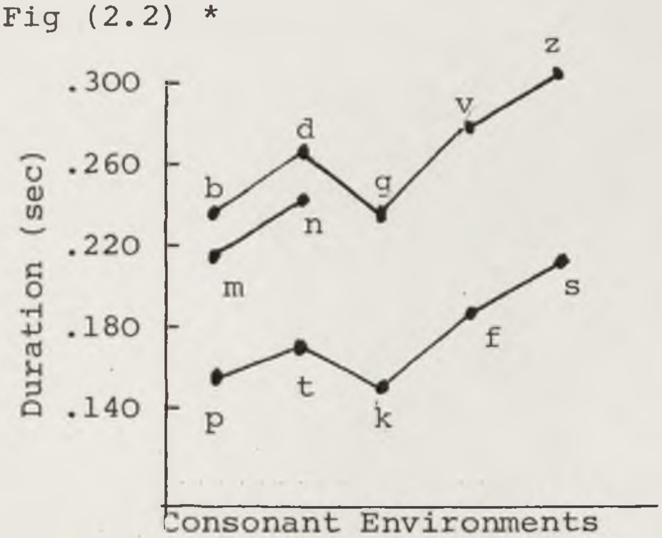
Belasco (1953) reports similar findings in French obtained by Delattre (1940) where the accented French vowel [ɛ] was the only vowel investigated followed by

Table (2.2) *Duration of Vowels in Various Consonant Environments. Vowels Pooled. All Values in Seconds.

Grouped Consonant Environments	
Voicing	
Voiceless (5)	0.174
Voiced (7)	0.253
Manner of Production	
Stop plosives (5)	0.203
Fricative (4)	0.234
Nasal (2)	0.232
Place of Articulation	
Bilabial (3)	0.205
Labio-dental (2)	0.234
Post-dental (5)	0.232
Velar (2)	0.198

* After House & Fairbanks (1953)

Fig (2.2) *



Mean duration of vowel, in various consonant environments. Vowels pooled.

* After House & Fairbanks (1953)

eighteen French consonants, but he gives no details about the experimental procedure followed by Delattre (op. cit.). Belasco (op. cit., p.1016) states:

> 'It was found that the duration of the vowel, measured in centiseconds, varied with the consonant that followed: p(14), t(15), k(16), l(21), n(23), m(25), s(24), ʃ(25), d(26), g(26), b(26), n(28), j(31), v(36), ʒ(37), z(38), r(42).'

Belasco (op. cit.), however, rejects the analysis of House & Fairbanks (op. cit.) of vowel duration from the point of view of voicing, manner of articulation and place of articulation as he believes that vowel duration is not dependent on these three consonant attributes but as he states:

> '... upon one attribute, the force of articulation - in which the degree of physiological energy required to pronounce an anticipated consonant will affect the length of a preceding vowel. The duration of a vowel varies inversely as the force of articulation of the following consonant.' (ibid).

In another classic work in the literature of vowel duration, Peterson & Lehiste (1960) set out to investigate the influence of both preceding and following consonants on the duration of stressed vowels and diphthongs in American English.

They used connected speech for the experiments. The material studied consisted of two sets of data. The first set involved 1263 words selected on the basis of frequency of occurance and recorded by one speaker in identical structure frame with fixed stress and pitch pattern. The second set consisted of 70 minimally different words, including 60 CVC words forming 30 minimal pairs, and 10 bisyllabic words constituting five additional pairs. The 70 words were uttered in a frame sentence spoken by five different speakers who used the same stress and pitch pattern.

Various techniques were used in the analysis, broad-band and narrow band spectrograms were made of the total set. The analysis also included; intensity curve with high frequency and low frequency pre-emphasis, a Grützt matcher pitch curve (Fo Curve), and a duplex oscillogram. But they state that the data measured from spectrograms form the primary basis for their observation.

Two separate measurements of vowel duration following voiced versus voiceless plosives were made;

the first included frication and aspiration and the second excluded both (for more details of the problems of segmentation faced by the two writers, see section 4.2.5.1).

Their overall analysis showed the following results:

1. Vowel duration before voiceless consonants are considerably shorter than those followed by voiced consonants. 'The ratio of vowel before voiceless consonant to vowel before voiced is approximately 2:3' (op. cit., p.700).

2. As for nasals they state, 'The homorganic nasals influence the preceding vowel in much the same manner as voiced stops.' (ibid).

3. Vowels before voiced fricatives have considerably longer duration than those preceding voiced plosives:

   '... the duration of the syllable nucleus before the voiced plosive was 30.0 scec, whereas the comparable duration before the voiced fricative was 37.9 csec.' (ibid).

4. The influence of the initial consonant upon the duration of the syllable nuclei seems to be negligible. They state:

   '... there is practically no

> durational difference associated with an initial /f/ - /v/ contrast; in the case of /s/ - /z/ and /č/[tʃ] - /j/[dʒ], the effect of voicing appears contradictory, the voiceless member of the pair being followed by a longer syllable nucleus in the case of /s/ - /z/ contrast, but by a shorter syllable nucleus in the case of the initial /č/ - /ǰ/ contrast.' (ibid).

As for initial plosives, they presented a special problem:

> 'If aspiration is considered part of the syllable nucleus, then voiceless plosives are regularly associated with longer syllable nuclei than voiced plosives; if, however, the duration of aspiration is discounted, the syllable nucleus following a voiceless plosive is usually shorter than that following a voiced plosive.' (ibid).

Denes (1955) set out to investigate whether, 'non-spectral characteristic such as duration can serve as the basis for phoneme recognition.' (op. cit., p.761).

He conducted an experiment to investigate how far duration relations actually determine the perception of voicing in speech. He selected a pair of words, "(the) use" and "(to) use" as test material on the basis that they consist of an identical sequence of phonemes except for the final consonant in each word, [z] and [s], voiced versus voiceless respectively. A number of speakers were asked to say these two words which were recorded and then analysed on spectrograph. Spectrograms showed that the vowel duration in the syllable with a voiced ending is much longer than in the other syllable and that there is a corresponding variation in the duration of the final consonant; the frication for [z] being shorter than that for [s]. The range of vowel duration for "the use" was 0.04 to 0.08, and for "(to) use" 0.12 to 0.2 sec. The consonant duration varied from 0.2 to 0.38 sec for "(the) use" and from 0.1 to 0.18 sec for "(to) use".

Accordingly Denes puts forward the question whether these durational effects could be used by the listener as cues for discrimination.

To answer such a question an exploratory experiment was carried out first. Tape recordings of the same words "(to) use" and "(the) use" spoken by one speaker were made and the final consonants were interchanged after making adjustments to their duration. It was found that the original voiceless [s] sounded a quite acceptable voiced [z] when shortened and attached to the front part of the original "(to) use" syllable. Similarly, the voiced [z] sounded clearly as voiceless [s] when lengthened and attached to the front part of the original "(the) use" syllable. This showed that:

> '... in the case of [jus] - [juz] pair, it is not so much the presence or absence of vocal cord vibration during the final sound as the sound durations which determine whether the listener will hear (the) use or (to) use.' (op. cit., p.761-762).

Another experiment was then carried out to find out:

> '... whether or not the perception of voicing of the final consonant was determined by the duration relations mentioned despite the fact that the sound at the end of the words was in every case identical.' (op. cit., p.762).

He states that it does not much matter whether the spectrum of the final consonant was harmonic or inharmonic because:

> 'The inharmonic spectrum would be recognized as [z] sound and the harmonic sound as an [s] sound as long as they

had the appropriate durations.' (ibid).
Accordingly, the inharmonic spectrum was selected for the experiment because it was easier to produce.

The Haskins pattern playback machine was used to synthesize the [ju] of the test material. Since the machine could not produce sufficient hiss-like frication noise, the word (the) use pronounced by a human speaker was recorded and the final inharmonic [s] like part of the utterance was separated and re-recorded a number of times. These frication sounds were then spliced to tape recordings of the rest of the words as synthesized onthe Haskins machine.
The durations of the central steady section and of the final noise section were the variables of the experiment and their values were decided by information obtained previously from spectrograms of human speakers, four different vowel durations of 0.05, 0.1, 0.15 and 0.2 sec and five final consonant durations of 0.05, 0.1, 0.15, 0.2 and 0.25 sec were chosen. A sufficient number of test items was made up so that every vowel duration occurred in combination with every fricative duration. This made 20 list items. Thirty three listeners were told that they would hear a randomized sequence of the words "(the) use" and "(to) use", and that they should indicate which of these two words they heard by writing down [s] or [z]. The question

of voicing was not mentioned. This showed the following results:

> 'the duration of vowels and of the final consonants have a definite and consistent influence on the perception of "voicing". The effect of the duration of the vowel on the perception of "voicing" is not independent of the duration of the consonant, and vice versa .....
> ... The perception of "voicing" of the final consonant increases as the ratio of the durations of final consonant to preceding vowel decreases.' (op. cit., p.763).

In discussing his data he reaches two conclusions. The first conclusion is that:

> '... duration relations can distinguish phonemic units, such as the unvoiced s as opposed to the voiced z, even when the spectral characteristics of the speech wave remain identical.' (op. cit., p.764).

The second conclusion is that:

> 'The particular relations which were found to affect the recognition of "voicing" apply only to English and may be different or non-existent in other languages.' (ibid).

Raphael (1972) designed experiments to extend the work started by Denes (op. cit.) by testing the effectiveness of vowel duration as a cue to the voicing characteristic of a variety of word final stops, fricatives and clusters.

The Haskins Laboratories' Pattern playback was used to generate the basic stimuli of vowel duration. The range of vowel durations, i.e. 150-350 msec, used for any specific series of stimuli was determined from investigation of real-speech samples of words spoken in isolation.

A similar procedure was followed in synthesizing the word final consonants and clusters. The oppositions chosen for the investigation are:

stops; /p - b/, /t - d/, /k - g/.

fricatives; /f - v/, /θ - ð/, /s - z/, /ʃ - ʒ/.

clusters; /pt - td/, /st - zd/, /ps - bz/, /kt - gt/, /ts - dz/, and /ks - gz /.

The same basic stimuli were used for words ending in both voiced and voiceless consonants. The voiced series was recorded first and then the voiceless one, with appropriate adjustments in formant transitions and cutbacks, frication durations, silent closure intervals, and release characteristics.

The stimuli of each series were randomized and played to 20 female and 5 male subjects who had to label which member of a minimal pair of words they heard for each stimulius played.

His results revealed total agreement with those obtained by Denes (op. cit.). He states:

> 'The results of the labeling tests revealed that, with one exception and regardless of the voicing cues used in their synthesis, all final consonants and clusters were perceived as voiceless when preceded by vowels of short duration and as voiced when preceded by vowels of long duration. That is, a final consonant or cluster synthesized with cues appropriate for voicing was perceived as voiceless when the vowel preceding it was of short duration, and as voiced when the preceding vowel was of long duration. A final cluster or consonant synthesized with cues for voicelessness was perceived in precisely the same way.' (op. cit., p.1298).

The only exception to these results was found in /ʃ/ - /ʒ/ opposition where the overall picture was one of confusion.

Zimmerman & Sapon (1958) studied this problem cross-linguistically using English and Spanish as test-languages. Spanish was chosen because it resembles English in that "voicing" is used to distinguish between several consonant phonemes like /p/ - /b/, /t/ - /d/, and /k/ - /g/ but unlike English [s] and [z] are used as allophones of /s/ and never occur in contrastive position nor is there a voiced counterpart of /tʃ/ or /f/. In consequence, they state that:

> 'On a quantitative basis, it can be said that Spanish makes less use of voicing as a distinctive feature than does English.' (op. cit., p.152).

The English material consisted of 38 monosyllabic words containing the vowel [i], followed by all the possible consonants. They were all in contrast on the basis of some feature of the final consonant yielding some items such as "neat, need, knees, niece ... etc." randomized in the list so that no contrasting pairs were contiguous. The Spanish material consisted of 90 bisyllabic paroxytonic words employing five vowel phonemes in the tonic position. These words were chosen so as to yield contrasts of all possible consonants e.g. pato, paro, palo, paso, pago, ... etc. The English list was read by two native speakers of American English of two different dialects and the Spanish list was read by two native speakers of two different but similar dialects of Spanish spoken in Latin America. Spectrograms were made for the test material and measurements were made of the duration of the stressed vowels in Spanish and English.

The overall results of their analysis showed the following:

1. Their findings for English were in accord with those obtained by Denes (op. cit.):

   '... vowels preceding voiced consonants are longer than vowels preceding unvoiced consonants, with the mean difference being 83.2 msec.' (op. cit., p.153).

2. For Spanish their finding showed:

   'Qualitatively, the findings for Spanish parallel those for English, with vowels preceding sonants being longer than vowels preceding surds. However, there is striking difference in quantitative terms, with the mean difference being only 18.2 msec in the Spanish vowels.' (ibid).

3. As for the range of vowel duration in the two languages, there is extremely large difference.

   '... the range in Spanish being 36.1 msec and the range in English being 136.0 msec.' (ibid).

The authors came to the following conclusions:

1. As regards the findings of Denes (op. cit.) that vowel duration constitutes a phonemic distinctive feature in English they state:

'... we can observe the lack of corresponding linguistic significance in Spanish not only from the small increase in length before sonants, but also in the extremely small overall variation in vowel length.' (ibid).

2. In consequence, they suggest the following hypothesis:

'... while there may be a physiologically induced lengthening of a tonic vowel preceding a sonant, the size of the effect is determined by linguistic structure.' (ibid).

They also claim that their attempt to rank the duration of vowels in accord with the notion of "force of articulation" as suggested by Belasco (op. cit.) yielded negative results.

House (op. cit.,p.1177) comments on the findings obtained by Zimmerman & Sapon (op. cit.) and states that:

> '... the lengthening effect of a following voiced consonant on a stressed English vowel does not obtain in Spanish, suggesting that durational variations are, in part at least, learned by talkers of English and not employed by talkers of Spanish.'

Delattre (1962) strongly criticizes Zimmerman & Sapon (op. cit.) and House (op. cit.) for having made the foregoing assumptions, and states that in the process of speaking, one constantly anticipates; in consequence, he attributes the shortening of vowels before voiceless consonant to the anticipation of greater force of articulation by the speaker for voiceless than for voiced consonants.

He also criticizes the way Zimmerman & Sapon had selected their material and states that it is unfair to compare Spanish paroxytonic bisyllabic words (pito/pido) with English oxytonic monosyllabic words (niece/knees) and because of this he states:

> 'No wonder the difference between surds and sonants is found to be considerably greater in English (Spanish /p/β, 93/130; English /p/b, 126/200).' (op. cit., p.1142).

He also believes that, contrary to what they state, the findings of Zimmerman & Sapon (op. cit.) revealed a perfect agreement with the notion of force of articulation as suggested by Belasco (op. cit.) because, as he states:

> 'Force of articulation representing a combination of two consonant factors; surd-stop versus sonant-fricative, the /p/β/, /t/,/ð/, /k/ /ɣ/ pairs represent precisely the contrastive factors strong force versus weak force.' (ibid).

Delattre (op. cit.) comes to two conclusions;

1. Apart from the abridging/expanding factor,

> 'Under the seven other factors,(1) variation in vowel length are physiologically conditioned.' (op.cit., p.1143).

2. As for the universality of these factors he states:

> '... that the chance for conditioning factors to be universal, to operate cross-linguistically, is far from negligible.' (ibid).

Chen (1970) investigated this phenomenon more extensively from the cross-linguistic point of view. Again, Chen's aim was to find out whether this kind

---

(1) See sections 2.2 and 2.3 for the eight factors of vowel duration suggested by Delattre (1962).

of durational difference is primarily brought about by linguistic structure or is inherent in the physiological process i.e. conditioned by: '... a physioacoustic constant governing the duration of vowels.' (op. cit., p.130).

He selected three languages besides English; French, Russian and Korean. The word list of each of the four languages consisted of minimal or near minimal pairs with identical prosodic pattern being kept constant. Each word was read by a native speaker six times in isolation and three times in alternation with its counterpart of the pair except for English in which case only three tokens were recorded for each word.

Measurements were made on the total of 376 broad-band spectrograms (300 Hz band-pass filter) produced by a Kay Sonagraph 6061-A.

His criteria of segmentation were based on those suggested by Peterson & Lehiste (1960) except for minor differences. For example he regarded the period of aspiration as part of the preceding plosives.

His results showed that in all the languages studied vowel duration is invariably longer before voiced than before voiceless consonants and states that results such as these could hardly be accidental.

Chen (op. cit.) also referred to data reported for Spanish and Norwegian showing the same trend but none of the languages compared showed so extreme a difference as in English; vowel duration being 0.61 or less than 2/3 before a voiceless consonant than before a voiced one compared with French 0.87, Russian 0.82, Korean 0.78, Spanish 0.86 and Norwegian 0.82.

Chen also compared the DLs[(1)] values of the above languages with respect to vowel duration differences in the phonetic contexts in question with those obtained by Stott (1935) and Henry (1948), as we shall see in section 2.6, and found that DLs values in English are far above the threshold values of perception compared with those obtained for the other investigated languages. See table 2.4.

In view of these observations Chen (op. cit., p.139) put forward two tentative conclusions;

> '(a) it is presumably a language universal phenomenon that vowel duration varies as function of the voicing of the following consonant, and (b) the extent, however, to which an adjacent voiced or voiceless consonant affects its preceding vowel durationwise is determined by the language-specific phonological structure.'

These conclusions reached by Chen (op. cit.), agree

---

(1) For more details of DLs see Section 2.6.

to a great extent, with those reached by House (op. cit.) and Zimmerman & Sapon (op. cit.).

Aziz (1976) investigated the influence of voicing on the acoustic duration of the preceding vowels in Kurdish. Monosyllabic and bisyllabic minimal pair words were chosen for the investigation embedded in a carrier sentence and read by the author who acted as the subject of the experiment. Mingographic traces of intensity high pass filtered at 500 Hz with a threshold of 20 dB were used for vowel duration measurements. His findings showed that in most cases vowels before voiced consonants were longer than before voiceless ones. In comparison with the findings of Peterson & Lehiste (1960), he states that the effect of voicing of the following consonant on the preceding vowel is not as great as that in American English with the ratio being 87%.

Klatt (1973), referring to the findings obtained by House & Fairbanks (1953), Denes (1955), House (1961) and Peterson & Lehiste (1960), reviewed earlier, established the following rule in American English:

> 'If a vowel is followed by a voiceless consonant within the same word, shorten the vowel by 25% (relative to its duration when followed by a voiced consonant within the same word).' (p. 1102).

Elert (1964), as reviewed by Lehiste (1970), established much smaller differences in vowel duration for Swedish due to the voicing of a postvocalic consonant e.g. short vowels followed by /t/ were 13 msec shorter than short vowels followed by /d/. Commenting on his finding Lehiste (op. cit., p.27) states:

> 'If a certain amount of increase before a voiced consonant is a universal feature, it is likely that its order of magnitude is closer to Elert's figure than to the large increases found in English.'

2.3.2 Place of Articulation

The influence of the place of articulation of the following consonant on the duration of the preceding vowel has also been extensively investigated by many phoneticians and in several languages. House & Fairbanks (op. cit.) found that vowels of American English preceding labio-dentals and post-dentals are generally longer than those preceding bilabials and velars, see table (2.2) and figure (2.2). But House (op. cit.) found this influence to be negligible.

The findings obtained by Peterson & Lehiste (1960) were rather different from those obtained by House & Fairbanks (op. cit.) and House (op. cit.). They made two separate measurements of short and long vowels of American English in the same consonantal environment. Their measurements showed that the durational variations of the vowels in question vary in the following order according to the place of articulation of the following consonant:

1. Short vowels:

   1. voiceless plosives = t > k > p
   2. voiced plosives = g > d > b
   3. voiceless fricatives = ʃ > s > f
   4. voiced fricatives = z > v
   5. nasals = m > n > n

2. Long vowels:

   1. voiceless plosives = t > k > p
   2. voiced plosives = d > g > b
   3. voiceless fricatives = ʃ > s > f
   4. voiced fricatives = ʒ > z > v
   5. nasals = ŋ > n > m

Zimmerman & Sapon (op. cit.) claim that they found no consistent pattern in terms of place of articulation of the following consonant regarding its effect on vowel duration. They listed average vowel durations before consonants in Spanish disyllabic paroxytonic words as follows; [p] 93 msec, [β] 130 msec, [t] 104 msec, [ð] 136 msec, [k] 108 msec, [ɣ] 137 msec. Delattre (op. cit.),however, relying on the same data mentioned above, asserts that contrary to what Zimmerman & Sapon (op. cit.) think, the measurements named above:

> '... reveal a perfect front-to-back pattern; the vowel being shorter before /pβ/ than before /fð/ than before /kɣ/' (op. cit. p.1142).

He also states that this is in remarkable agreement with the data reported by Peterson & Lehiste (op. cit.). Lehiste (1970), however, is dubious about this sort of comparison because as she states:

> 'It cannot be concluded from these data whether the lengthening before [βðɣ] set is due to voicing or frication.' (op.cit., p.20).

Fischer-Jørgensen (1964) investigated extensively the extent to which vowel duration can be affected by the place of articulation of the vowel itself, the preceding consonant and the following consonant.

She selected Danish non sense syllables, the first list contained the vowels [i], [u], [y] followed by [b], [d], [g] preceded by [h] or by the same consonant as that following the vowel. The second and third lists contained all possible consonants followed by [udə] or [idə] but she states that the first list was used as the basic one. The test material contained 3520 vowels, 2106 post vocalic consonants and 1386 cases of open intervals (open syllables) after initial stops. The words were spoken by seven speakers 6 or 12 times each. Five of the subjects were male and two of them were female but all of them were Danish phoneticians who were accustomed to working with nonsense words. A pitch (Fo) meter and an intensity meter (Frøkjær-Jensen) were used. Spectrograms were also made but were taken as a subsidiary technique used in cases of doubt and to help in the identification of some traces on mingograms. The period of frication following voiced plosives was excluded from the duration of vowels which is in contradistinction to the principle adopted by Peterson & Lehiste (1960) and House (1961).

Her results showed that three factors of place influence the duration of vowels in this type of material:

'(a) the place of articulation of the vowel itself; [u] is on the whole longer than [i].

(b) the place of articulation of the following consonants; vowels are, on the whole, shorter before [b] than before [d] and [g].

(c) the specific vowel-consonant combination; there is an evident tendency u(d) > u(g) > u(b), a weaker tendency y(g) > y(d) > y(b) and a slight tendency i(g) > i(b) > i(d).' (op. cit., p.191).

In the discussion of her data she states that the Danish vowels [i], [y], [u] have no special feature which could explain these relations as particularly Danish phenomena and since some of these relations have also been found in other languages, '... it is, therefore, a plausible hypothesis that they are of cross-linguistic validity.' (op. cit., p.200).

Maak (1953), as reviewed by Lehiste (1970), found that for German front vowels were longer before labials and velars than before dentals and back vowels were longest before labials and shortest before velars. He also studied the influence of the place of articulation of a preceding consonant on the duration of a following vowel and found that the vowel is proportionally longer, the closer its point of articulation is to that of the preceding consonant. This observation, however, has not been confirmed by any other studies.

2.3.3 Summary

It seems from the preceding arguments that the effect of voicing on the duration of the preceding vowel, that is, longer duration of vowels before voiced than before voiceless consonants, is cross-linguistically valid. Hence, it is, in part, at least, a language universal phenomenon determined by an inherent characteristic of the articulatory process. Yet, the extent of this effect varies from one language to another and thus can be determined by the language specific phonological structure. Investigation of the acoustic variation of vowel duration associated with different manners of articulation of the following consonants seem to have yielded in most cases, a consistent pattern and the general tendency is voiced fricatives > voiced plosives > nasals > voiceless fricatives > voiceless plosives, whereas variations of vowel duration associated with the manner of articulation of the preceding consonant seem to be negligible.

On the other hand, investigations into variations of vowel duration due to the place of articulation of the following consonant seem to have yielded, in most cases, an inconsistent pattern. Vowel lengthening according to Delattre's (op. cit.) front-to-back pattern does not seem always valid, particularly in specific vowel-consonant combinations as shown by Fischer-Jørgensen (op.cit.). This suggests that more investigations will be needed to establish whether or not variations of vowel duration according to different places of articulation may constitute a language-universal phenomenon.

2.4 The Correlation Between Stress and Vowel Duration

As has been stated earlier, this study is not the place of a comprehensive and detailed discussion of the complex phenomenon of stress. As a consequence, and for the purpose of this study, the discussion will be confined to the acoustic correlates of stress to shed some light on two interesting areas in the literature of stress that have direct concern with our present analysis; firstly, to see how far vowel duration stands as an acoustic correlate serving in the perception of stress in relation to other acoustic correlates intensity, fundamental frequency and frequency spectrum; secondly, to assess the influence of stress as a phonetic phenomenon on the acoustic duration of vowels in stressed versus unstressed syllables. Thus, neither the physiological (articulatory) nor the perceptual correlates will be given any emphasis.

2.4.1 Vowel Duration as an Acoustic Correlate of Stress:

The acoustic correlates of stress have been specified by many phoneticians and in several languages as: duration, fundamental frequency, intensity and frequency spectrum or formant structure of the speech sound (Fry (1955), (1958), (1964), Jassem (1959), Nyqvist (1961), Lehiste (1970). Many experiments have been conducted and in several languages to see whether the listener uses all these acoustic correlates as concomitant cues in the perceptual realization of stress or there is a primacy of a specific correlate over the others.

Before reviewing some of these experiments it is important to note that the terms "duration" and "vowel duration" are used synonymously by the writers concerned. Fry (1958) made all the measurements in his three studies as well as the variations of duration, intensity, fundamental frequency and frequency spectrum on the vowel portion of a syllable in words like "subject", "digest" where the shift of stress from the first to the second syllable is associated with a change of function from noun to verb and states:

> '... the differences between a noun and a verb were carried out almost entirely by the "vowel" stretches of the wave motions and it was evident that in synthesizing test material the whole range of variation might justifiably be made in the "vowel" stretches.'
> (op. cit., p.131).

Fry (1955) investigated the influence of duration and intensity on the perception of linguistic stress patterns. The test material chosen was a group of English words like "subject", "digest" in which a change of function from noun to verb is commonly associated with a shift of stress from the first to the second syllable. Spectrograms were used to determine the vowel duration and intensity ratios and this information was applied in making up a perceptual test using the Haskins playback synthesizer. Listeners' judgements of stress could be correlated with variations in the intensity and duration ratios.

The results of these experiments showed the following:

> '(1) duration and intensity ratios are both cues for judgements of stress, (2) the vowel segments show the major differences in duration and intensity with a shift of stress, and (3) duration ratio is more effective cue than intensity ratio.' (op. cit., p.768).

Other experiments were also conducted by Fry (1958) to investigate, this time, the effects on stress judgements of three acoustic correlates, viz, duration, intensity and fundamental frequency. The same English word-pairs of the type "subject", "digest" were chosen as test material. Speech stimuli were synthesized using the Haskins playback synthesizer in which these physical correlates could be controlled and varied over a considerable range and to use this material to construct listening tests which were carried out by large groups of subjects.

The results of these experiments confirmed his findings (Fry 1955) on the significant role of vowel duration. He states:

> 'The importance of the duration ratio is confirmed by the fresh data presented here; it seems that in English, in a considerable variety of conditions, changes of vowel duration ratio can swing listener's perception of strong stress from the first to the second syllable in the type of disyllable that has been considered.' (op. cit., p.151).

As for intensity he states:

> 'The data show no case in which change of intensity ratio caused a complete shift of the stress judgement from first to second syllable.' (ibid).

As regards fundamental frequency he states:

> 'Change in fundamental frequency differs from change of duration and intensity in that it tends to produce an all-or-none effect.' (ibid).

Fry (1964) investigated the role of a fourth acoustic correlate viz; the role of vowel formant structure in the perception of stress.

Versions of the noun-verb word pairs "object", "contract", "subject" and "digest" were synthesized in which there was systematic variations of frequency of the first and the second formant in the first syllable of "object" and "contract" and "digest" and the second syllable of "object" and "subject".

Variations in vowel duration ratio were introduced in the same stimuli in order to provide a means of estimating the weight to be assigned to the changes in formant structure.

The fundamental frequency of the periodic sound was kept constant at 120 Hz throughout the experiment. The overall intensity was regulated so that the maximum intensity in the two syllables of each test word might be equal; a constant difference of 6 dB between F1 and F2 was maintained throughout the experiment i.e. the amplitude of F1 was greater by 6 dB.

Stress judgements were obtained from one hundred subjects, who were native speakers of Southern English.

His results showed as he states:

> 'There is no doubt that in the conditions of this experiment, the weight of the duration cue is very considerably greater than that of the formant structure cue.' (op. cit., p.308).

In contrast to the findings obtained by Fry (1955, 1958) Lieberman (1960) seems to emphasize the role of intensity rather than duration or fundamental frequency. He also used word-pairs of the same sequence (SUBject, subJECT) to investigate the acoustic correlates of stress in American English.

He conducted an experiment in which,

> '... the fundamental frequency, relative amplitude, duration and integral of the amplitude with respect to time of the stressed and unstressed syllables were measured and related to the aural perceptible stress pattern.' (op. cit., p.451).

Lieberman (op. cit.) made two types of comparison, in the first case he compared the stressed and the unstressed syllables of the same word and in the second case he compared the stressed syllable with its unstressed counterpart in the other word of the noun-verb pair.

In the first case he found that the stressed syllable had a higher fundamental frequency than the unstressed syllables in 99% of the cases, a higher peak envelope amplitude in 87%, and a longer duration in 66%. In the second case he found that the stressed syllable had a higher fundamental frequency in 72% of the cases, a higher peak envelope amplitude in 90%, and a longer duration in 70%.

For the first set of results, however, Lieberman seems to be aware of the fact that:

> '... the effect of the cases where the stressed and unstressed syllables had vowels of differing intrinsic intensities may, in part, account for this difference.' (op. cit., p.454).

Still, even if we take the second set of results as being the more reliable and where the comparison is feasible, in contrast to the findings of Fry (op. cit.) the role of intensity seems more important than that of duration. However, it should be more emphasized here that Lieberman's approach was analysis only whereas Fry obtained crossovers from perceptual experiments, so in Lieberman's experiment intensity can very well be a strong acoustic correlate but not necessarily a strong cue for the perception of stress.

Morton & Jassem (1965) found that the role of fundamental frequency is more significant in the perception of stress than that of either intensity or duration. Nonesense syllables of the form /sisi/, /soso/ and /sasa/ were synthesized with specific variations of the appropriate parameters. Listening tests were also made where 60 subjects had to give their responses to different stimuli. The word forms were selected in order to avoid the complications of intrinsic intensities of vowels having different phonetic quality.

Their results showed that:

> 'The first and overwhelming effect is
> that any syllable with a fundamental
> different from the normal 120 c.p.s.
> has the stress marking.' (op. cit., p.172).

As for the effect of intensity, it was small compared to that of fundamental frequency.

As regards duration they state:

> '... more people placed the stress on
> the longer syllable when one was shortened
> further, but there was a relatively high
> proportion of times when the short syllable
> was marked as stressed.' (op.cit., p.175).

The findings of Morton & Jassem (op. cit.) are in total agreement with the statement made by Lehiste (1970) that:

> 'In many languages higher fundamental
> frequency provides a strong cue for
> the presence of stress.' (op.cit., p.125).

To Lehiste (op. cit.) intensity plays an ambiguous cue in the perception of stress, whereas for duration she states:

> 'The presumed generality of the feature, sometimes implied in the literature, may be due to the fact that duration is indeed a stress cue in many western European languages that have been subjected to instrumental phonetic analysis.' (ibid).

In their search for the acoustic correlates of stress in the connected speech of some native and non-native speakers of Australian English, Adams & Munro (1978) confirm Lehiste's (op. cit.) observation about the minor role of intensity on one hand, and, on the other hand, their data totally agree with the findings of Fry (op. cit.) on the significant role of duration.

Their subjects were of two groups, one native Australian English speakers and the other, foreign. The assessment was made independently by 10 adjudicators who were non-linguist native speakers of English. They were asked to listen to the readings of 12 items of meaningful connected material recorded by the two groups of subjects and to indicate the words or syllables in each utterance which seemed to them to receive sentence stress.

The second stage of their experiment included analysis of duration, fundamental frequency and intensity.

Their results showed that of the (16) subjects (native and non-native) tested:

> 'Stress was positively correlated with fundamental frequency in 7 individuals, with amplitude in 4 individuals and with duration in 13 individuals.' (op. cit., p.143).

The measurements of the three acoustic parameters of the syllables stressed by these subjects revealed as they state that:

> '... duration was by far the most frequently used cue and that amplitude was the least used.' (op. cit., p.125).

2.4.2 The Influence of Stress on Vowel Duration

We have seen in the previous section that vowel duration, as an acoustic correlate, plays an important role in the perception of stress. In this section we shall review some of the experiments made to investigate the influence of stress as a phonetic phenomenon on the acoustic duration of vowels.

It has been known that in English stress can, to a considerable extent, condition the acoustic duration of vowels. Parmenter & Trevino (1935) as reviewed by Lehiste (1970) established that in English an average stressed vowel is approximately 50% longer than an average unstressed vowel. Fry (1955) made measurements of vowel duration in sequences of stressed versus unstressed syllables (mentioned earlier in the previous section) and found that vowel duration is considerably longer in stressed than in unstressed syllables, whereas the consonants were not materially affected by the presence or absence of stress.

Tiffany (1959) made duration measurements of (10) American English vowels; [i], [I], [e], [ɛ], [æ], [o], [ʊ], [u], [ɑ], and [ʌ]. These vowels were said in meaningful sentences by two different groups of adult American speakers. Each word containing any of these vowels was said in two different conditions of "sense stress". Contrastive sense stressing was obtained by devising six more or less meaningful sentences, each of which contained two different [h - d] words. These sentences were presented to the reader in pairs, with different words underlined in each member of the pair, in such a way that if read properly the two readings would produce both a stressed and an unstressed reading of the same word in the same context, e.g.

They <u>hid</u> under the <u>hood</u> of the car.

<u>They</u> hid <u>under</u> the hood of the car.

The first group of subjects consisted of 10 phonetically trained males and the second consisted of (10) phonetically untrained males.

Duration measurements were made on spectrograms. As for segmentation he states:

> 'In general the duration of the vowel was defined as the duration of at least two clear-cut formants in the appropriate frequency regions.' (op. cit., p.308-309).

His results showed that for both the trained and untrained subjects vowels in stressed syllables are significantly longer than unstressed syllables.

Delattre (1966) studied the influence of stress on vowel duration cross-linguistically. English, German, Spanish and French were chosen as test languages. For each of the four languages, five minutes of extemporaneous speech by native speakers were obtained.

The investigation included three conditioning factors; syllable weight referring to stressed versus unstressed syllables, syllable position referring to final versus non-final syllables and syllable type referring to close versus open syllables.

Spectrograms of the material were made with narrow-band filtering and amplitude display. A broad phonetic transcription was made by referring to the original recordings as well as to spectrograms. Stressed syllables were identified and sense group boundaries were determined. Measurements of syllable length in the four test languages were made on the basis that:

> 'Syllabic division generally occurs during the closure of the closest consonant between vowel peaks, so that a portion of that closest consonant is in the first syllable and the other portion in the second syllable.' (op. cit., p.184).

As regards syllabic weight (stressed versus unstressed) his results showed the following:

1. Stressed syllables are longer than unstressed syllables in all four languages.
2. Though the influence of stress on syllable length is clearly marked, it is not equally marked in all four languages. He states:

   > 'English has the widest ratio of syllable lengths from stressed to unstressed, German has a narrower ratio, and Spanish the narrowest.' (op. cit., p.189).

3. As for French, though it showed by far the largest ratio, i.e. not a wide range of ratios, he attributes this large ratio to the fact that stressed syllables in French (since it is fixed

in the final syllable) are influenced by the combined effect of syllable weight and syllable position.

In his spectrographic study of vowel reduction in Swedish, Lindblom (1963) measured formant frequencies and duration for 8 Swedish vowels uttered by a male speaker in three consonantal environment under varying timing conditions.

His investigation showed that timing is the primary variable in determining the reduction of sounds and claims that:

> '... it is immaterial whether a given length of the vowel is produced chiefly by the tempo or the degree of stress. Duration seems to be the main determinant of the reduction. (op. cit., p.1780).

Delattre (1969) in his cross-linguistic study of vowel reduction in English, German, Spanish and French disagrees with Lindblom (op. cit.) and states that:

> 'We must continue to consider stress and tempo the primary determinants of vowel reduction, and duration a product of stress and tempo and, therefore, a secondary determinant of vowel reduction.' (op. cit., p.298).

In his review of the causes of vowel reduction he states that:

> 'Reduction correlates with stress. Weakly stressed or "unstressed" vowels suffer more obscuration than strongly stressed ones ... ... reduction also correlates clearly with vowel duration - the shorter the vowel, the more obscure it tends to become.' (op. cit., p.297).

2.4.3. Summary

It seems obvious from the previous sections that vowel duration is an important acoustic correlate of stress and plays an efficient role in the perceptual realization of stress; it often outweighs the role of fundamental frequency in this respect. It also seems evident that the influence of stress on vowel duration is indisputable; vowels are considerably longer in stressed than in unstressed syllables in several languages indicating the cross-linguistic validity of this phenomenon.

This may imply that vowel duration can be regarded as one of the phonetic exponents of stress and stress may, to a considerable extent, condition the acoustic duration of vowels.

Also, it must not be forgotten that the shortening of vowels caused by weakness or lack of stress has its consequential effect on vowel reduction.

2.5 The Influence of Gemination on Vowel Duration

2.5.1 Introduction to Gemination

The question whether a geminate consonant is considered as one long consonant or two identical (abutting) consonants has been a controversial issue for many years. In the literature of gemination there are two different views; the first is the two-phase theory which was first proposed by Sievers (1876); it suggests that the process of producing geminate consonants involves a rearticulation of the consonant; thus this process has two phases; the first signals the end of one syllable and the second signals the beginning of another.

Sievers did not base his claim on any instrumental data but rather on auditory and kinesthetic perception.

The second view, which was enhanced by Rousselot's findings in (1891), opposing Sievers' view, rejects the concept of rearticulation of consonants and denies any difference between geminates and long consonants. Rousselot (1891), as reviewed by Lehiste et al. (1973), using equipment available at that time, investigated this phenomenon in the Gallo-Roman dialect of Cellefrouin. He found no evidence for a rearticulation in the geminate consonants; they appeared twice as long and twice as intense as the corresponding short consonants.

Stetson (1951) investigated single and what he calls long consonants in English sequences like "I do/I'd do, I lie/I'll lie" etc. His analysis also involved intra oral air pressure tracings and tongue and lip marker tracings. Each pair of his test material was said by four subjects who were not aware of the fact that the same consonant in single and double form were present in each pair.

Stetson (op. cit.) found clear evidence for double articulation. Both the tracing of lip movements and the intra oral air pressure showed two maxima for the abutting consonants involved.

In Hungarian, geminates occur in intervocalic position within words rather than at word boundaries as in the case of Stetson's test materials. Hegedus (1951), as reviewed by Lehiste et al. (op. cit.) studied single and geminate consonants in Hungarian and found no evidence for rearticulation of the Hungarian geminates.

Delattre (1971) made a cross-linguistic study of gemination in four languages viz., English, German, Spanish and French. He defines gemination in this study as the meaningful perceptual doubling of a consonant phoneme. His test materials were chosen so as to give gemination across a word boundary in all four languages, for example, in English 'will lend' versus 'will end', similar to those chosen by Stetson (op. cit.). The utterances were recorded by native speakers of each language and spectrograms were made on which consonant duration were measured (in centiseconds). Cineradiography of selected utterances was done. Speech synthesis was used to test by ear what consonant durations or ratios of consonant duration are appropriate in each language in distinguishing geminate consonants from single ones.

His results showed that duration is, as he states:

> '... a major attribute of gemination across word boundary in all four languages, but the duration contrasts are wider in the two Latin languages than in the two Germanic ones and are narrowest of all in English.' (op. cit., p.112).

He also found that intensity measurements made from spectrograms as well as cineradiography showed that geminates can be distinguished from single consonants by having two phases in their articulation. Perceptual tests, on the other hand, which were carried through with synthetic speech, confirmed that consonant duration is a major cue for the perception of gemination.

Al-Ani (1978) calls geminate consonants in Arabic identical clusters and states:

> '... this phenomenon of indissolubility of geminate consonant clusters creates an obstacle in the operation of syllabic segmentation in Arabic.' (op. cit., p.121).

He also states in the same reference:

> '... the difficulty lies in the fact that a syllable boundary signal should occur between the geminated consonants. However, this is not physically possible neither on the phonetic nor on the acoustic level, precisely because the physical and acoustic nature of consonants allows only one sound element in such a situation and not two.... Yet, for the sake of consistency with the phonological system of the language, the geminated consonant is represented by two identical symbols in the transcription.' (ibid).

Blanc (1952) states that gemination in Arabic involves prolongation of the continuants and a longer closure of stops.

Mitchell (1962) calls geminate consonants in Arabic "doubled consonants" and states:

'Any Arabic consonant may be doubled. Except when final, a doubled consonant must be pronounced at least twice as long as its single counterpart and is characterized by greater muscular tension in the articulating organs.' (op. cit., pp.19-20).

Nasr (1960) regards geminate consonants in Lebanese Arabic as long consonants that take relatively longer time to be completely produced than the shorter ones.

2.5.2 The Influence of Consonant Clusters and Geminate Consonants on the Duration of the Preceding Vowel:

Delattre (1962) believes that [æ] is shorter in "pack" or "pat" than in "pad" but is shorter still in "pact". He assumes that the anticipation of a greater effort for the articulation of the cluster [kt] shortens vowels more than the anticipation of the single consonant [k] or [t]. Similarly, Spanish [i] is considerably shorter in "pinta" than in "pina" or "pita".

Josselyn (1901), as reviewed by Colin Mortimer (1977), used equipment available at that time to investigate the influence of gemination on vowel duration in Italian. He found a compensatory shortening of the preceding vowels occurred.

Delattre (1971), reviewed in section 2.5.1, with reference to the close relation that exists between a short following voiced consonant and a preceding long vowel, was curious to know whether geminate consonants would be preceded by shorter vowels than the corresponding single consonants. But to his surprise he found that they were not significantly shorter. He states:

> 'This is unexpected because vowels are shorter before a voiceless consonant than before a voiced one - an analogical condition with respect to the anticipation of a great effort.' (op. cit., p.112).

In all the languages investigated vowels before geminates are on the average only slightly shorter than vowels before single consonants. He reports these average ratios of vowels before geminates to those before non-geminates in the four languages; Spanish .94 to 1, English .96 to 1, French .96 to 1 and German .97 to 1.

Nooteboom & Slis (1972) investigated what they call phonetic duration of Dutch long versus short vowels and found that consonants following a short vowel have a consistently longer duration than consonants following a long vowel.

Thananjayajasingham (1976) made an experimental study of the duration of intervocalic voiceless double stops that occur in the colloquial Tamil speech. His spectrographic data showed that:

> '... the duration of the closure was very long if the stop was preceded by a short vowel and considerably less if the stop was preceded by a long vowel.' (op. cit., p.150).

2.5.3 Summary

No matter whether a geminate consonant is considered to be one long consonant or a cluster of two identical consonants, in both cases there seems a very close relation existing between a following short consonant and a preceding long vowel and a relatively long following consonant and a short preceding vowel. Similarly, a consonant cluster (of two identical or different consonants) is usually preceded by a relatively shorter vowel than that preceding a single consonant. Consequently, it seems most likely that a vowel preceding a geminate consonant is shorter than when it is preceding its counterpart single consonant.

2.6 The Perception of Duration

The acoustic correlate of the timing of articulatory sequences, as stated by Lehiste (1970), is the time dimension of the acoustical signal and the perceptual correlate of this time dimension is the perception of duration. Many psychoacoustic studies have been made to deal with various problems of the perception of duration and the literature as a whole presents three interesting areas for discussion and further investigation. These three areas can be specified as follows:

1. The minimal differences of duration that a human listener can detect which have been termed the just noticeable differences (JNDs) or the difference limens (DLs) and whether these differences should be expressed as absolute values or as ratios.

2. The shortest perceptible time interval between two successive sounds that a human listener can perceive.

3. How the DL in duration is affected by other suprasegmental features, i.e. how far the perception of one suprasegmental feature is influenced by other suprasegmental features or more specifically the role of fundamental frequency and intensity in the perception of duration.

For the purpose of this study the discussion will be confined to the first area where experiments have been reported on the DL for duration by Stott (1935), Henry (1948), Small & Campbell (1962) and Ruhm et. al. (1966).

According to Weber, as stated by Lehiste (op. cit.), the ratio between the stimulus increment and the reference stimulus is a constant; therefore the Weber ratio $\Delta T/T$, that is, change in duration over reference duration, is constant, and these constant ratios apply to all sense modalities. But Stott (1935), Henry (1948) and Ruhm et al., (1966) found that these constant ratios (Weber ratios) do not perfectly describe perception of duration.

Stott (1935) conducted an extensive experiment the aim of which was:

> '... to make an accurate and thorough discrimination of the constant or time-order errors (C.E.s), which occur in comparing short tonal duration (intervals of time filled with continuous tone). (op. cit., p.741).

From his 524 subjects about 99,480 judgements were obtained. He used a constant stimulus throughout his study and states:

> 'A complete stimulus presentation consisted of a standard duration and a variable duration separated by an interval of silence of 1.5 sec.' (op. cit., p.747).

His results showed that the Weber ratios are not consistent. Referring to the data obtained by Stott (op. cit.), Henry (1948) states that his ratio drops from 0.145 for a duration of 200 msec to 0.115 for 400 msec and remains at this value for intermediate durations, then tends to rise again with durations longer than one sec.

The experiment of Henry (op. cit.) was mainly concerned with the nature of the difference limens for duration of very brief sounds ranging from about 30 msec to nearly 500 msec in length.

His subjects were seven students (three women and four men). He used a tone of 500 Hz at 50 dB above the threshold level. He also used a range of intensity from 20 to 80 dB and a range of frequency from 125 to 2000 Hz to test the effect of these variations on the DL of duration.

His results concerning the Weber ratios and the DLs for duration tested at seven reference durations showed clear differences from those obtained by Stott (op. cit.). Henry (op. cit.) thinks that these differences are probably due to different instrumentation and experimental procedures employed in the two experiments.

A more recent and sophisticated study in this respect was made by Ruhm et al., (1966). They conducted an experiment the aim of which they state as:

> '... to assess the differential sensibilities to acoustic signal duration under various combinations of reference duration, sensational level and signal frequency .... to determine whether hearing impairment, ostensibly due to cochlear pathology, affects such discrimination.'
> (op. cit., p.371).

Their data were obtained from three groups of ten subjects each of an equal number of men and women. One group, with which we are mostly concerned here, was given short duration signals ranging from 40 to 100 msec at 1000 Hz at 50 dB sensation level.

Their results showed Weber ratios and difference limens considerably smaller than those obtained by Stott (op. cit.) and Henry (op. cit.) as shown in table (2.3) adapted from Lehiste (op. cit.) which summarizes relevant information from three experiments in which the reference durations are within speech range. Lehiste (op. cit.) thinks that the research technique employed by Ruhm et al. (op. cit.) was probably more conducive to testing the limits of the auditory sensitivity of the subjects. Accordingly, she puts forward the suggestion that,

> '... the difference limens established

> by Ruhm et al. (1966) represent the limit of perceptibility under optimal conditions, whereas it appears likely that in speech condition, the just noticeable differences established by Henry and Stott may apply.' (op. cit., p.13).

Lehiste (op. cit.) comes to the following conclusion:

> 'It appears that in the range of durations of speech sounds - usually from 30-300 msec - the just noticeable differences are between 10 and 40 msec.' (ibid).

In the light of Lehiste's suggestion, Chen (1970) combined the findings of Stott (op. cit.) and Henry (op. cit.) and compared them with his data in a composite table. He regarded the average vowel duration in each of the languages he had investigated as a reference duration equivalent to the reference duration, T, in Stott and Henry's data and regarded the mean difference of vowel duration as a function of the voicing of the following consonants (1) as equivalent to the ΔT. He compared this ΔT with the DL in Stott and Henry's data as shown in table (2.4) adopted from Chen (op. cit.) Columns E and D are

---

(1) For more details of the results obtained by Chen (op. cit.) see section 2.2.1.

equivalent to A and C respectively.

2.6.1 Summary

The perception of duration is the perceptual correlate of the time dimension of the acoustical signal. Many experiments have been conducted on the DL of duration, the most relevant of which to this study are Stott (1935), Henry (1948) and Ruhm et al. (1966). These experiments showed that neither Weber's ratios nor the absolute DL are consistent in the three studies. They are much smaller in the most recent one. This may be due to different instrumentation and experimental procedures employed in the three studies.

Nevertheless one may follow Lehiste's (1970) p.13 suggestion that the range of the DL duration may be taken as between 10 and 40 msec in sequences ranging from 30 to 300 msec.

It may also be mentioned that DLs established by Stott (op. cit.) and Henry (op. cit.) are more convenient to apply to speech conditions and those established by Ruhm et al. (op. cit.) probably represent the limits of perceptibility under optimal conditions.

Table (2.3)* Weber Ratios and Mean Absolute Difference Limens for the Perception of Durations Established in Three Studies (in msec).

* After Lehiste (1970) p. 12

	Stott (1935)		Henry (1948)		Ruhm et al. (1966)	
T	ΔT/T	Absolute DL	ΔT/T	Absolute DL	ΔT/T	Absolute DL
32			0.281	8.99		
40					0.0575	2.3
47			0.203	9.54		
60					0.0283	1.7
77			0.208	16.02		
80					0.0263	2.1
100					0.0260	2.6
110			0.196	21.56		
175			0.188	32.90		
200	0.142	28.4				
277			0.172	47.64		
400	0.120	48.0				
480			0.143	68.64		
600	0.115	69.0				

Table (2.4)* Comparison of mean differences of vowel duration in Korean, Spanish, Russian, Norwegian, English and French, with Weber ratios and Absolute DLs for comparable reference durations. (H) = Henry; (S) = Stott.

A Reference duration in msec	B Weber ratio $\Delta T/T$	C Absolute DL in msec	D Mean difference in msec	E Av. Vowel duration in msec	
110(H)	0.196	21.56	28	105	Korean
			18	118	Spanish
			29	145	Russian
175(H)	0.188	32.90	33	165	Norwegian
200(S)	0.142	28.4	92	192	English
400(S)	0.120	48.0	53	380	French

* After Chen (1970)

CHAPTER THREE

MYODYNAMIC AND AERODYNAMIC CORRELATES OF VOWEL DURATION

3.1 Introduction to the Processes of Speech Production

This chapter reviews and discusses some interpretations of the acoustic characteristics of vowel duration found in the literature. In interpreting the acoustic variations of vowel duration, phoneticians are concerned with two areas; whether these variations are language universal or language specific i.e. whether the factors determining these variations are inherent in the physiological process of articulation or imposed by the phonology of the language. No matter which area dominates, the discussion entails associating these variations with the myodynamic and aerodynamic aspects of speech production. It is essential, therefore, that a review or a discussion as such should be prefaced by an introduction to the processes of speech production of which the myodynamic and aerodynamic stages are vital and indispensible.

In discussing the relation between phonetics and the brain, Laver (1968) suggests three stages in the processes of speech production;

(a) The ideation stage where the selection of the appropriate semantic content of the message takes place.

(b) The neurolinguistic programme stage which includes:

> '... the organization of the neural program of the grammatical, lexical, phonological and phonetic characteristics of the selected message.' (op. cit., p.66).

(c) The myodynamic performance stage which is, as he states:

> '... the temporally-ordered myodynamic performance of the neurolinguistic program.' (ibid).

Fant (1973) adds other important stages which comprise the aerodynamic and acoustic processes. He specifies three categorical stages in the speech communication chain; a. production, b. technical medium and c. perception. In "production" he specifies five terminal stages;

1. Intended meaning of message.

2. Message sentence form.

3. Neural production programme.

4. Myodynamic activity.

5. Aerodynamic and acoustic processes.

More recently Catford (1977) has looked at these stages more closely. He splits Fant's No.5 stage into two separate stages. He specifies five phases (stages) in the sequence of events responsible for the process of creating speech sounds:

> '1. neurolinguistic programming; selection, sequencing and timing of what follows.
>
> 2. neuromuscular phase: transmission of outbound (efferent) neural pulses, firing of motor units and contraction of individual muscles.
>
> 3. organic phase: postures and movements of whole organs.
>
> 4. aerodynamic phase: dilation, compression and flow of air in and through the vocal tract.
>
> 5. acoustic phase, propagation of sound waves from speaker's vocal tract.' (op. cit., p.4-5).

For the purpose of this study the attention will be focused on the myodynamic stage which is defined here as the movements of the articulators, equated with articulation, and the aerodynamic stage as the ones most pertinent to the creation of speech sounds observed in the acoustic stage. Besides, the activities of these stages are relatively accessible to phoneticians either kinesthetically and/or instrumentally.

3.1.1 The Myodynamic Stage

This stage, as has been stated, involves the postures and movements of the speech organs responsible for the different and constantly changing configurations that are assumed by the organs. In other words it is the stage responsible for the process of adjusting the shape of the vocal tract which is called articulation and the individual movements of the speech organs (articulators) which is called the articulatory movement. Catford (op. cit.) believes that the myodynamic stage has a certain primacy in the processes of speech production and states:

> 'Speech is a human activity, and it consists quite specifically of movements and postures of certain organs. The investigation of these organic events is clearly the most direct way of studying speech as a human behaviour.'
> (op. cit., p.10).

Laver, however, believes that there are some restraints imposed on the myodynamic performance. These can be of two types:

> '... restraints inherent in the neuro-muscular system, and restraints habitually imposed by the speaker's own voluntary speech behaviour. (op. cit., p.70).

According to Laver, the inherent restraints are those which include:

> 'factors of neuromuscular anatomy and physiology ... and involve spatial and temporal considerations.' (op. cit., pp.70-71).

Habitual restraints, on the other hand, are of two types; 'firstly, language specific, and secondly, personal and non-linguistic.' (ibid). Laver concludes that:

> '... much can be inferred from the myodynamic evidence of such aspects as overlapping motor commands, features of seriality, duration and rhythm.' (ibid).

On the basis of the restraints imposed on the myodynamic activity suggested by Laver (op. cit.), two types of myodynamic factors are to be considered in this study that are likely to determine certain acoustic variations of vowel duration; factors inherent in the physiological process of articulation and language specific factors that are imposed by the phonological system of the language. These two factors have been suggested as determinants of some acoustic variations of vowel duration by many phoneticians whose studies have been reviewed in Chapter Two.

Many techniques have been employed to detect myodynamic activity. These include dynamic palatography, cineradiography, electromyography, optical glottography, electrical laryngography and others. In this study, besides the electrical laryngography used to investigate some aspects of laryngeal activity, we present criteria for obtaining myodynamic data for the supraglottal constriction derived from aerodynamic variables (pressure and airflow). These will be fully discussed in Chapter Five.

3.1.2 The Aerodynamic Stage

This stage is essential and cannot be dispensed with in the processes of creating speech sounds, since, as stated by Scully 1970, it 'provides the link between the articulatory and the acoustic stages of speech communication' (op. cit., p.14). The importance of the aerodynamic stage stems from the fact mentioned by Catford (op. cit.) that:

> '... organic postures and movements do not themselves generate sounds; they merely create the aerodynamic conditions, for the generation of speech sounds is in all cases an aerodynamic process.' (op. cit., p.11). (His emphasis).

Catford, however, has overlooked here an important fact concerning the interaction between the myodynamic and aerodynamic conditions in the creation of sound source. For instance, the muscular state of the vocal folds is relevant to the "voice" source as well as the aerodynamic conditions.

Catford goes on to describe the importance of the aerodynamic conditions and states:

> 'Some of the organic activities cause pressure changes in the vocal tract which result in a flow of air; other organic activities regulate this flow in ways that create sounds, either by channelling the airflows through narrow spaces, generating the audible hiss of turbulence, or by allowing it to burst forth in rapid periodic puffs generating the sound of voice, and so on.' (ibid).

For the purpose of this study, two aerodynamic variables are considered viz; pressure and airflow. These two variables are essential in order that, as stated by Scully (op. cit.):

> '... the speaker's vocal tract partially converts an inaudible airstream into vibrating audible movements of air.' (ibid).

Such aerodynamic activities have been suggested by Scully (1974), as we shall see later, to provide conditioning factors of acoustic vowel duration particularly between vowels followed by voiced versus voiceless consonants.

3.2 Interpretations of Vowel Duration in Terms of Myodynamic and Aerodynamic Conditions

It is quite evident from the previous sections that the roles of both the myodynamic and the aerodynamic stages of the speech production processes are so vital in creating the speech sounds observed in the acoustic stage that it is very difficult to attribute the acoustic outcome to either of them alone. Scully (1979) states that:

> 'Myodynamic and aerodynamic conditions interact, neither can be said to dominate in creating sound sources.' (op. cit., p.37).

This may imply that when interpreting any acoustic durational variations of vowels both stages should be referred to. In the literature of vowel duration, however, early attempts to interpret these acoustic variations did not seem to be aware of the significant role of the aerodynamic conditions; they were mostly based on articulatory assumptions. Some recent studies employing modern instrumentation and new experimental methods have shown how, besides the indisputable role of the myodynamic conditions, the role of the aerodynamic conditions is not less significant.

In this chapter we shall review some of these attempts and hypotheses to interpret the acoustic durational differences of vowels advocated by some phoneticians.

3.2.1 Articulatory Distance

This hypothesis was first suggested by Jespersen who was quoted by Lindblom (1968, p.23) as follows:

> '... the duration of a vowel is a function of its articulatory "distance" to adjacent consonants.'

Jespersen's hypothesis was substantiated by the data reported by House & Fairbanks (1953), Maak (1953), Fischer-Jørgensen (1964) and Lindblom (1968).

The findings of House & Fairbanks (op. cit.), reviewed in sections 2.2 and 2.3.1, showed that the longer duration of open vowels is directly related to the size of mouth opening and inversely related to tongue height. This could be explained as they state:

> '... on grounds of varying extent of articulatory movement with correspondingly

varying time.' (op. cit., p.134).

Maak (op. cit.) for German and Fischer-Jørgensen (op. cit.) for Danish advance a similar concept. In discussing her data, reveiwed in section 2.3.2, Fischer-Jørgensen (op. cit.) explains the differences of vowel duration associated with the place of articulation of the vowel itself as well as that of the following consonants in terms of articulatory distance. She approves Maak's (op. cit.) concept and states:

> 'It seems more promising to look for a common cause of duration of consonants and vowels. In these cases the extent of the articulatory movement is probably a decisive factor. This is also the factor advocated by Maak; a longer movement takes more time.' (op. cit., p.203).

But she criticizes Maak because he operates exclusively with the distance between the place of articulation of the vowel and consonants, and disregards the factor of coarticulation. She refers to her own data and states:

> 'In the combination of [ub] he considers the distance between the lips and the back of the tongue as a reason for lengthening of the [u]. But this distance

> is of course irrelevant, since the closure of the lips can be made independently of the tongue movement. One should not, therefore, expect u before b to be longer than before d but rather the opposite, as found in the Danish material.' (ibid).

In the case of open versus close vowels, Fischer-Jørgensen totally agrees with the explanation advanced by House & Fairbanks (op. cit.) and states:

> '... the extent of the movement can also be used to explain the difference of vowel length according to the degree of opening.' (op. cit., p.207).

On the basis of this argument, she advances the following hypothesis:

> '... the motor command for the timing is the same irrespectively of the quality of the vowel, but the execution of the command may be delayed owing to the movements to be made.' (ibid).

It is open to question, however, whether the motor command for the timing of vowels having different phonetic qualities is the same, as implied by Fischer-Jørgensen (op. cit.), and whether the only difference is in the delayed execution of the command because of the articulatory movement involved. This extremely difficult question should be subjected to more myodynamic investigation.

Lindblom (1968) in his investigation of Swedish long and short open versus close vowels, reviewed in section 2.2, found that it is not only the movement of the tongue which affects the inherent characteristics of vowels but the movement of the jaw could also have a substantial effect in this respect. The dynamic model of lip and mandible which he had constructed showed that:

> '... the dynamic behaviour of the mandible gives rise to the dependence of acoustic vowel duration on the degree of vowel opening.' (op. cit., p.24).

Lisker (1974), referring to the relation between intrinsic duration of vowels and the degree of opening as reported by House & Fairbanks (op. cit.) and Petersen & Lehiste (op. cit.), largely agrees with the hypothesis of Lindblom (op. cit.) and states:

> 'The relation reported has been understood as a mechanical effect due to a temporal constraint on the movement of the relatively large mass of the lower jaw, with that of the tongue sometimes also implicated; if open or low vowels involve more jaw movement

than do the close vowels, then the greater so-called "intrinsic duration" of the former is a natural consequence, provided we believe that in speech we regularly operate close to the limits set by the physical constraints on the mechanism.' (op. cit., p.226).

Lisker (op. cit.) also investigated intrinsic duration of American English as reported by Peterson & Lehiste (op. cit.) in relation to first formant frequencies. Taking short and long vowels separately he found:

'... a tendency for duration to increase with increasing first formant frequency; at least [I] and [ʊ] are shorter on the average than [ɔ], and [i] and [u] are likewise shorter than [ɔ] and [æ] ... the relation of [æ] to [a] is consistent with Perkell's (1969) x-ray finding that although the tongue is higher for [æ] than [a] the mandible is lower for the former.' (ibid).

Chen (1970), in his attempt to explain the differences of vowel duration before voiced versus voiceless consonants argues against the articulatory distance hypothesis and states:

> 'In a transformed sense, however, assuming that vowels are normally voiced vowels would be one degree more "distant" from a voiceless consonant involves the distinction in one additional aspect of articulation, namely the discontinuance of voicing. If our reasoning is correct, we would expect the vowel to be lengthened before a more distant voiceless consonant. But the contrary is true.' (op. cit., p.140). (our emphasis).

Two reasons make us believe that Chen's argument here is invalid; firstly, he confines his "reasoning" to the glottal activity and totally ignores the concomitant supraglottal activity where the articulatory movement actually applies, as in the previous arguments. Secondly, it is difficult to make sweeping generalization while explaining certain acoustic aspects where different articulatory parameters are involved. Furthermore, what is probably adequate to interpret the intrinsic durational difference in open versus close vowels is not necessarily adequate to interpret the durational difference that results from, for instance, the voiced/voiceless contrast of the following consonant.

3.2.1.1 Summary

The articulatory distance hypothesis provides interpretations of the acoustic variations of vowel duration in purely myodynamic terms; in terms of the extent of the articulatory movement i.e. the longer the articulatory movement that articulators must make to assume a certain configuration responsible for the constriction of the following consonant, the more time it takes and hence the longer the preceding vowel becomes. This hypothesis provides a plausible explanation for vowel duration variations as a function of the open/close dimension; it is quite probable that certain articulatory parameters such as the mandibular movement and tongue height are decisive in delaying the constriction of the following consonant, resulting in a longer acoustic duration for the preceding open vowel.

3.2.2 Force of Articulation and Articulatory Energy Expenditure

The hypothesis of force of articulation originates from the concept first advocated by Meyer (1904) who is quoted by Lindblom (op. cit., p.22) as asserting:

> '... the temporal organization of speech sounds is determined by the amount of physiological energy that is consumed in producing them.'

Belasco (op. cit.) is specifically concerned with the relation between the energy expended to produce the following consonant and the duration of the preceding vowel. He claims that the data of Delattre (1940) for French and House & Fairbanks (1953) for American English, as reviewed in section 2.3.1, showed that the length of the vowel varied inversely as the degree of physiological energy required to produce the following consonant. Accordingly, he advances the following hypothesis:

> '... the anticipation of a consonant requiring a "force" of articulation will tend to shorten the preceding vowel since more of the total energy needed to pronounce the syllable is concentrated in the consonant.' (op. cit., p.1016).

Delattre (1962) is in total agreement with Belasco's concept of force of articulation and specifically attributes the shorter duration of vowels before voiceless consonants to the anticipation of greater articulatory effort needed for the articulation of voiceless than that for voiced consonants.

The argument raised by Delattre (op. cit.) on the dichotomy of voiceless/voiced consonants as articulated with strong versus weak muscular energy is well known in the literature and has often been termed fortis referring to voiceless consonants and lenis referring to voiced consonants. The terms tense and lax have also been suggested to refer to long and short vowels respectively.

For the purpose of this study the concept of force of articulation will be discussed in as much as it concerns the dichotomy of voiceless/voiced or fortis/ lenis of the following consonant and tense/lax vowels to see the plausibility of force of articulation as a reason for the variations of acoustic vowel duration.

3.2.2.1 Fortis/Lenis Consonants and Tense/Lax Vowels

We shall start by reviewing some of the concepts on the dichotomy of fortis/lenis consonants as regards the acoustic variations of the preceding vowel duration and then proceed to the discussion of the dichotomy tense/lax as regards the durational difference between long and short vowels.

According to Gimson (1970, p.32):

> 'A voiceless/voiced pair such as[s,z] are distinguished not only by the presence or absence of voice but also by the degree of breath and muscular effort involved in the articulation ... the voice opposition may be lost, so that the energy of articulation becomes a significant factor.'

Consequently, Gimson (op. cit.) suggests that [s] is defined as strong or fortis and [z] as weak or lenis. In accordance with this dichotomy Gimson asserts:

> 'When the RP plosives occur finally in a syllable their value is determined largely (since the voicing factor is not strongly operative) by the length of the syllable which they close. It is a feature of RP that syllables closed by fortis consonants are considerably shorter than those which are open or closed by a lenis consonant.' (op. cit., p.152).

Scully (1971) argues against Gimson's assertion that [s] is a fortis consonant articulated with more muscular energy and stronger breath force than the lenis [z]. In a myodynamic and aerodynamic comparison of English [s] and [z] her data showed that Rc max. (maximum tongue constriction resistance) and Ac min. (minimal cross-sectional area of constriction) are not significantly different for the two consonants. This implies that [s] and [z] are articulated with approximately the same degree of tongue occlusion. She states:

> 'The discussion of Rc and Ac as parameters of tongue occlusion showed that a constant value for Rc and Ac at two different air

> flow rates should be interpreted as indicating more occlusion at the lower flow rate. Since /s/ has a higher air rate than /z/ with the same values of Rc and Ac, it follows that /s/ is, if anything, less occluded than /z/. So the tongue constriction is smaller in area for /z/ and the articulation is more extreme. Tense-lax or fortis-lenis, if it is a valid distinction at all in the supraglottal articulation of /s/ and /z/, must operate in the opposite direction to that expected; /z/ is, if anything, fortis and /s/ is, if anything, lenis.' (op. cit., p.194).

Malécot (1970) comes to the conclusion that force of articulation is a proprioceptive impression rather than strong articulatory energy. He states:

> 'Force of articulation is a significant attribute of consonants and enters into the lenis-fortis opposition in such pairs as /p/ : /b/ and /s/ : /z/. It is a case of synthesia, in that it has little or nothing to do with articulatory energy but is rather a proprioceptive impression based primarily on intra-buccal air pressures resulting from the air-valving

action of the glottis, the occlusion or constriction of the buccal passage, and the velopharyngeal sphincter, and perhaps also involving closure duration.' (op. cit., p.1588).

In an earlier paper, Malécot (1968) correlates the dichotomy of fortis/lenis with intra oral pressure. He states:

> 'The fortis (unvoiced) consonants are characterized by relatively high pressure, their lenis (voiced) cognates by low pressure.' (op. cit., p.95).

According to Malécot (op. cit.) it is the anticipation of the high intra oral pressure and not the greater muscular energy of the following consonants that shortens the preceding vowel. He states:

> 'We apparently shorten it in anticipation of higher pressure, which we erroneously interpret as greater articulatory effort, and vice versa.' (ibid).

Fischer-Jørgensen (1968) considers the dichotomy of fortis/lenis to be correlated with the duration of closure period and organic pressure. In a comparative study of voicing, tenseness and aspiration in stop consonants in French and Danish, she found that French /p, t, k/ can be treated as fortis consonants because they are characterized by longer closure period, higher lip pressure and higher intra oral pressure than their /b, d, g/ counterparts.

Nevertheless, what is striking in this comparison is that in Danish this relation is quite the opposite; Danish /p, t, k/ are characterized by a shorter closure period, less lip pressure (in the case of /p/) and insignificant intra oral pressure compared with their /b, d, g/ counterparts. This strongly suggests that what is fortis in French might be considered as lenis in Danish and vice versa.

Lisker (1974) argues against the hypothesis that shortening of vowels before voiceless consonants is due to their greater force of articulation. He states that although electromyographic and velocity measurements have shown that voiceless stop closures begin earlier and are excecuted more rapidly than closures for the voiced stops:

> 'It is, odd, however, that this advancement in the timing of closure can be explained by the fortis feature.' (op. cit., p.230).

He believes that such explanations should include the vital laryngeal activity. He states:

> '... the explanation based on the assumed fortisness of the voiceless stops says

> no more than that the voiceless stops are produced with an earlier and more rapid closure than the voiced ones. The concomitant laryngeal change, abduction of the arytenoids, is tacitly taken to be secondary to the supra-glottal event.' (ibid).

Raphael (1975) attributes the durational differences found in vowels preceding voiced/voiceless consonants not to the muscular energy of the following consonants as has often been suggested but to the muscular energy involved in the production of vowels themselves. In an electromygraphic investigation he found that:

> '... the acoustically measured durational differences long observed between vowels preceding voiced and voiceless consonants are primarily controlled physiologically by motor commands to the muscles governing the articulators which are active in the formation of vowels. The timing of these commands is generally such that after the peak of the articulatory-muscular activity has been reached, the articulators are maintained (although not statically) in shapes and positions appropriate for vowels somewhat longer when they precede voiced consonants.' (op. cit., p.32).

The explanation of the acoustic differences in vowel duration before voiced/voiceless consonants in terms of the muscular energy involved in the production of the vowels themselves is not very usual in the literature but has often been referred to when explaining the durational difference found between long and short vowels, often termed tense/lax vowels respectively.

Thomas (1947) classifies American English vowels in terms of the tense/lax dichotomy and states:

> 'In general, tense vowels are longer than lax vowels in the same context.' (op. cit., p.121).

House & Fairbanks (op. cit.) explain the same variations in terms of varying extent of articulatory movement and claim that their findings shed considerable doubt on the assertion by Thomas (op. cit.). In a later paper, however, House (1961) rules out an overall articulatory explanation of his data and states, as reviewed in section 2.2, that the average duration of vowels increases with vocalic tenseness and vocalic openness. He attributes the durational difference between close and open vowels to tongue height and that between long and short vowels to muscular energy and states:

> '... the measured diminution of duration associated with lax vowels, however, might

be attributed to a reduction in the vocal effort expanded in producing the vowels.' (op. cit., p.1177).

Jones (1976) confines the dichotomy tense/lax to the case of close vowels and asserts that one can feel the throat tenser when pronouncing an English long close vowel /i:/ than when pronouncing its short counterpart /i/.

Delattre (op. cit.) objects to the terms lax and tense for vowels and replaces them by the terms abridging/expanding respectively because of the following:

'(a) There is no evidence, either articulatory or acoustic that the shorter vowels /I U ə ɛ/ are more lax than the others. In fact lax correlates with diphthongization, and the vowels that diphthongize most are the longer ones. The terms lax and tense should be reserved for the comparison of languages. All French vowels are tense, all American vowels are lax. (b) Any implication that lax/tense might be the cause of short/long is badly misleading.' (op. cit., p.1143, footnote 4).

Chomsky & Halle (1968) explain this dichotomy on an articulatory basis and state that tense vowels are executed with a greater deviation from the neutral or rest position of the vocal tract. They rely on cineradiographic data reported by Perkell (1965) whom they quote as stating:

> '... the pharynx width remains relatively stable throughout the tense vowels whereas there is a change in this width during the lax vowels ... It is as though the tongue shape in the lower pharynx is relatively unconstrained during a lax vowel , and is free to be influenced by the adjacent phonetic segment. For a tense vowel, on the other hand, the tongue position and shape in this region, are rather precisely defined.' (op. cit., p.325).

In an ultrasonic study of tenseness in American English vowels, Mackay (1977) found that tense vowels showed advancement of the anterior pharyngeal wall compared to lax vowels having similar tongue height and frontness but he states that the tenseness distinction is more salient among the higher (closer) vowels than among the lower (opener) vowels.

3.2.2.2 Summary

The hypotheses of force of articulation and articulatory energy expenditure provide interpretationsof the acoustic durational variations of vowels in terms of the articulatory energy expended in producing voiceless/voiced consonants and tense/ lax vowels (among other phonetic contexts). It has been hypothesized that the shortening of vowels found before voiceless consonants is due to the anticipation of stronger muscular energy involved in the articulation of voiceless consonants than that of voiced ones (Belasco (op. cit.), Delattre (op. cit.)). On the other hand, shortening found in short vowels is suggested as being due to a diminution of the muscular energy expended in producing their counterparts long vowels. (House (op. cit.) among others).

It seems from these arguments that the concept of force of articulation is not as simple as it has been described in purely myodynamic terms; it is far from being simply correlated with articulatory and muscular energy expended in producing certain speech sounds but implies many aerodynamic aspects incorporated with myodynamic aspects to bring about what is often intuitively felt as articulatory energy.

Force of articulation and articulatory energy expenditure do not seem to provide tenable explanations of durational differences of vowels before the so-called fortis/lenis consonants and those for the tense/lax vowels because the explanations of both dichotomies have failed to account for the concomitant glottal acitivity as well as the aerodynamic implications of interactions between the glottal and supraglottal activities.

3.2.3 Contrasting Aerodynamic Conditions

The hypothesis of contrasting aerodynamic conditions is mainly concerned with the problem of explaining the dichotomy voiced/voiceless consonants and its implications for the acoustic differences of the preceding vowel duration.

Scully (1971) states that the acoustic differences in duration and intensity of noise for /s/ and /z/ observed on spectrograms arise because of differences in intra oral pressure and airflow created by the glottal adjustment and not because /s/ is fortis and /z/ is lenis. These aerodynamic differences are consistent with the same subglottal pressure for the test words /sls/ and /zlz/ and with the vocal folds kept adducted for /zlz/ but abducted during the /s/ segment of /sls/.

The observations of Scully (op. cit.) of the contrasting values of intra oral pressure and airflow for voiced versus voiceless consonants and the speculation as to their cause are confirmed in many other studies. Slis & Cohen (1969) review most of the relevant studies and state:

'As higher intra oral pressures are measured with voiceless consonants than with voiced ones, it is possible for the pressure drop across the glottis with voiceless consonants to be too small to support vibration (e.g. Dam ste, 1961; Fischer-Jørgensen, 1963; Malécot, 1966; Subletny et al., 1966; Slis & Dam ste, 1967).' (op. cit., p.147).

Lisker (1965) states:

'... we are entitled to suppose that a difference in supra glottal pressure is the consequence of a difference in mode of laryngeal operation, rather than sign of an independent fortis-lenis contrast.' (op. cit., p.3.14).

Slis (1970) reports measurements of intra oral pressures and subglottal pressures for voiced versus voiceless fricatives and plosives in Dutch. His findings show that the intra oral pressure both in normal speech and shouting is considerably higher during voiceless than during voiced consonants whereas in whispered speech these differences are hardly observable. For subglottal pressure, on the other hand, the measurements indicate no significant difference between voiced versus voiceless fricatives and plosives and suggest that the peak values of subglottal pressure are independent whether the consonant is voiced or voiceless. He states:

> 'We may, therefore, conclude that differences in intra oral pressure do not have their origin in differences in subglottal pressure; on the contrary during shouting we even observed a tendency to a higher subglottal pressure in voiced consonants than in voiceless consonants, while the intraoral pressure was lower.' (op. cit., pp.199-200).

The articulatory model which Slis (op. cit.) had constructed predicted equal oral constrictions with voiced and voiceless consonants whereas acoustically the voiced interval proved to be shorter than the voiceless interval. He states:

> '...; this discrepancy between acoustical and hypothetical articulatory events leads to the assumption that the vowel before a voiceless consonant ends acoustically even before the mouth is closed. We attributed the early ending of the voice to a decrease of the pressure drop across the glottis before the actual closing of the mouth. This decrease should be due both to an increase of resistance in the oral

> constriction during the closing gesture of the mouth and to a simultaneous opening of the glottis.' (op. cit., p.197).

However, the measurements of closure duration of the lips showed that they were different for /p/ and /b/ implying that the glottal action is not the only feature contrasting these two plosives.

The concept of contrasting aerodynamic conditions as determining factors of the acoustic variations of vowel duration before voiced versus voiceless consonants was first suggested by Scully (1974). In a synthesizer study of aerodynamic factors in speech segment durations her results showed the following:

> '... a special glottal adjustment, different from that for vowels in the case of some speakers, may be made for voiced fricatives because of the acoustic requirements. Although this partial opening of the glottis is assumed to take the same time as a wider opening, it results in a greater vowel duration and a smaller consonant duration for voiced fricatives because of the different aerodynamic conditions created in the two cases.'
> (op. cit.,pp.231-232).

She also found that the myodynamic articulatory occlusive time as defined by Ac (tongue tip) is not equal to the acoustic occlusive segment shown by Ao (voice source).

This view has been clarified in a recent paper, Scully (1979). In a comparison between model prediction and real speech on fricative dynamics, she constructed a model of speech production which comprises the final stages of speech production viz; the myodynamic, aerodynamic and acoustic stages, on the assumption that local aerodynamic conditions depending on the myodynamic activity throughout the respiratory system are crucial in determining the various acoustic patterns. For real speech words like "hiss" and "his" were analysed. Spectrograms and mingographic traces of Fo and intensity high pass filtered at 3.6 KHz as well as intensity full frequency were used for measurements of consonant and vowel durations with thresholds of 10 and 20 dB respectively. See table 3.1. The aerodynamic data (intra oral pressure and airflow) were obtained for the same items (for supraglottal constriction). The myodynamic data concerning the tongue constriction area and the myodynamic timing were inferred from the aerodynamic data where oral pressure was above atmospheric level. The traces suggest that the speaker has used the same subglottal pressure as indicated by peak airflow for /-h/ and peak intensity for /-I-/ which are the same for /hIs/ and /hIz/. the acoustic results as shown in table 3.1 suggest that vowel duration is considerably longer before /z/ than before /s/ and the duration of /s/ is longer than /z/. The myodynamic and aerodynamic measures as shown in table 3.2 suggest that the minimum tongue constriction area and the timing from mid /-h/ to mid-fricative are the same for /hIs/ and /hIz/. Values for oral airflow and oral pressure are significantly different, with some overlap.

These results suggest that the myodynamic programme for the supraglottal articulation is the same for "hiss" and "his". Consequently, Scully (op. cit.) rules out explanations for the observed acoustic differences in myodynamic terms and suggests an explanation based on airflow traces in conjunction with the inferred myodynamic and aerodynamic measures as she states:

> 'After the minimum of airflow for [-I-], airflow rate rises: sharply for [-s-] less sharply for [-z-]. At this time oral pressure is atmospheric, there is no significant supra-glottal constriction, and glottal area controls airflow. Thus the traces indicate that the vocal folds begin to be abducted at the same moment for both [-s-] and [-z-]. There is no aerodynamically steady vowel segment and differences in vowel duration

do not seem explicable in terms of later vocal-fold movement for [-z-].' (op. cit., p.45).

According to Scully (op. cit.) the above explanation is valid when vowel duration is intrinsically controlled but, on the other hand, as she states:

> '... if relative durations of vowels and fricatives are crucial for the perception of /Vs/ versus /Vz/ contrast in English, then segment durations are likely to be adjusted myodynamically for phonologically "long" (her commas) vowels.' (op. cit., p.46).

Myodynamic data as inferred from pressure and airflow traces for the words "peace", "pease", "pass" and "parse" suggest that the tongue constriction is delayed for /-z-/ relative to /-s-/ by about 30 msec when /a/ precedes and by about 55 msec when /i/ precedes. Additional vowel and fricative duration differences between /Vs/ and /Vz/ can be accounted for on aerodynamic grounds.

3.2.3.1 Summary

The hypothesis of the contrasting aerodynamic conditions is the antithesis of the concept of force of articulation in that it accounts for the acoustic difference of vowel duration not in terms of how much energy is expended in producing them but in terms of the different aerodynamic conditions (intra-oral pressure and airflow) created above the glottis, behind the supraglottal constriction by the glottal adjustment which must be different in the case of voiced from that of voiceless consonants.

Since the subglottal pressure of both voiced/ voiceless consonants, as shown by Slis (1970), as well as the myodynamic programme for the supraglottal articulation of words containing voiced/voiceless consonants, as shown by Scully (1974) and (1979), may, for some examples at least, have no significant difference, it is very likely that the different vocal folds adjustment for voiced/voiceless consonants would not directly bring about the acoustic differences of the preceding vowel duration but via the different aerodynamic conditions created by this adjustment in the supraglottal activity.

Nevertheless, the myodynamic programme for the supraglottal constriction could be deliberately planned by the speaker for phonological purposes. Here, the created myodynamic conditions interact with the different aerodynamic conditions to enhance the acoustic differences of vowel duration as crucial cues for perception.

Table 3.1* Acoustic measures for 6 tokens each of /hIs/ and /hIz/ for the English speaker. Mean values and, below, ranges. Duration in msec.

(a) Vowel duration		(b) Fricative duration		(c) Time from mid-[h] to mid-fricative	
s	z	s	z	s	z
105	145	100	45(50)	200(205)	210
100-110	130-160	95-110	35-60	195-210	205-220

(a) from full frequency intensity with a threshold of 20 dB;

(b) from intensity high-pass filtered at 3.6 KHz with a threshold of 10 dB;

(c) mid-[h] is defined by a minimum in the full-frequency intensity; mid-fricative is defined by (b) above.

* After Scully (1979).

Table 3.2* Myodynamic and aerodynamic measures for 12 tokens each of /hIs/ and /hIz/ for the English speaker. Mean values and, below, ranges.

(a) tongue constriction area at mid-fricative in cm 2		(b) time from mid-[h] to mid-fricative in msec	
s	z	s	z
0.090	0.085	230	225
0.06-0.12	0.05-0.13	205-250	210-245

(c) oral airflow at mid-fricative in litre/min		(d) oral pressure at mid-fricative in cm H2O	
s	z	s	z
14.5	11.0	5.6	4.1
9.5-20.o	7.5-16.0	3.9-6.6	2.9-5.0

Mid-fricative is at minimum tongue constriction area. Mid [h] is at airflow maximam.

* After Scully (1979)

3.2.4 Laryngeal Adjustment

The hypothesis of laryngeal adjustment was first suggested by Halle & Stevens (1967). It is mainly concerned with the adjustment and positioning of the vocal folds during the production of voiced versus voiceless consonants and the implications of this on the acoustic duration of the preceding vowels. They argue that in both cases the vocal folds are separated but the width of that separation is smaller during the entire vibratory cycle in the case of voiced consonants than that of voiceless consonants where there is little or no glottal vibration. This is based on the assumption that values of glottal resistance and intra-oral pressure are different in both cases. Observation based on airflow traces for vowels preceding voiced versus voiceless consonants obtained by Klatt (1967) and Klatt, et al. (1967) suggest that the rate at which vocal folds positioning can be achieved is relatively slow for the production of the constricted consonant following a vowel. They maintain that this rate is slower still in the case of voiced consonants because the observed slight abduction of the vocal folds here is a deliberate action by the speaker to maintain voicing under adverse conditions.

On the basis of the above assumptions, Halle &

Stevens (op. cit.) put forward the following hypothesis. They state:

> 'In the case of a voiceless consonant following a vowel, it might be argued that the necessary wide separation of the vocal cords can be achieved more rapidly than the more finely adjusted smaller separation for a voiced consonant. Furthermore, the abduction maneuver for a voiceless consonant can be assisted or speeded up by the increased mouth pressure that occurs in such a consonant.' (op. cit., p.269).

In accordance with this hypothesis they suggest the following interpretation for the acoustic difference in vowel duration before voiced versus voiceless consonants in English:

> 'The longer laryngeal adjustment time required for a voiced consonant would necessitate an increased duration of the preceding vowel; the consonantal constriction cannot be effected before the vocal cords are positioned in a way that will guarantee uninterrupted vocal-cord vibration during the constricted interval.' (op. cit., p.269-270).

Partial support for this explanation has also been reported in the same paper. Vowel duration before voiced consonants was compared to that before nasal consonants assuming that a nasal consonant does not require that particular vocal folds adjustment. Their results showed that a vowel is consistently shorter before a nasal consonant than before a voiced plosive.

Chomsky & Halle (1968) accept the above hypothesis and state that spontaneous voicing during voiced consonants involves quite different adjustments than does spontaneous voicing during vowels. They totally agree with the interpretation suggested by Halle & Stevens (op. cit.) and state:

> '... the very common lengthening of vowels before voiced obstruents can be explained on the ground that it requires time to shift from the glottis configuration appropriate for vowels to that appropriate for obstruents.' (op. cit., p.301).

Fischer-Jørgensen (1968) does not accept this hypothesis and states that the laryngeal adjustment in question may be a mechanical consequence of the articulatory constriction, which does not require particularly long time.

Chen (1970) has tested the plausibility of the laryngeal adjustment hypothesis assuming that:

> '... if adjustment rate is indeed responsible for the vowel length variation, then in a vowel-sonorant-obstruent string, we would expect the sonorant alone to vary in length, the vowel remaining constant. The obvious reason is that in such a sequence the vowel is separated from the [± voice] obstruent and is, therefore, shielded from the immediate effect of the laryngeal adjustment which takes place between the sonorant and the obstruent.' (op. cit., p.148).

However, the experiment he performed showed that it is not the case. His results had shown, as he states:

> '... the lengthening or shortening of the consonantal environment was not limited to the immediately preceding sonorant alone but rather spread to the vowel segment as well: vowel duration varied notably even when separated from the obstruents by an intervening sonorant.' (op. cit., p.159).

To test this hypothesis further he argued that if voiced consonants require, as he put it:

> '... a delicate adjustment in the width of the opening between the vocal cords, we would expect the PCA (posterior cricoid-arytenoid) muscles to be active relatively long before

> a voiced consonant ... on the other hand, we would expect the same muscles to show a higher but somewhat later EMG peak before a voiceless consonant since for the voiceless consonant the glottis is wide open and relatively little time is needed for the simple abduction of the vocal cords.' (op. cit., p.151).

The electromygraphic data for the test words: tap/tab, tat/tad, tack/tag showed no difference either in timing or in intensity of signals from PCA muscles.

Lisker (1974) does not accept the laryngeal adjustment hypothesis because as he states:

> '... the available electromygraphic and fiberoptic data provide little indication of laryngeal change before voiced stops, but they do indicate that the arytenoid cartilages are subject to an adjustment in rough synchrony with the closure for voiceless stop production.' (op. cit., p.230).

Relying on the data reported by Sharf (1962), Lisker (op. cit.) argues that if we assume that:

> '... vowel lengthening is required to allow time for glottal readjustment before voiced

stop closure, then this would seem to imply that the shorter vowels ought to show a greater increase in duration than the longer vowels. But in fact, from Sharf's (1962) data it appears that the longer a vowel is preceding voiceless stops, the greater the durational increment added for voiced stops.' (ibid).

3.2.4.1 Summary

The laryngeal adjustment hypothesis provides interpretations in both myodynamic and aerodynamic terms for the acoustic variations of vowel duration before voiced versus voiceless consonants; the longer duration found before voiced consonants is assumed to be due to a readjustment of the vocal folds vibration different from that appropriate for vowels. This delicate adjustment is assumed to require more time than the simpler, less delicate adjustment needed in the case of voiceless consonants; this is based on the assumption that values of glottal resistance and intraoral pressure are different in both cases; the relatively wider separation in the case of voiceless than that of voiced consonant is assumed to be assisted or speeded up by the higher intraoral pressure built up during the production of voiceless consonants.

Neither electromyographic nor fiberoptic data give any confirmation of such laryngeal adjustment in the case of voiced consonants.

3.2.5 Temporal Compensation

The temporal organization of speech production has been studied by many phoneticians to see whether the articulatory events are programmed in terms of single phonemes temporally organized at the neuro-linguistic programming stage of speech production and executed in the limited time allocated for each or in terms of higher-level articulatory units each of which may comprise one or more of these phonemes. The temporal compensation hypothesis has been suggested to tackle this question. It has been shown (Kozhevnikov & Chistovich (1967), Slis (1967), (1968), Lehiste (1971), Huggins (1971)) that the durations of adjacent phonemes are negatively correlated; everything being constant, an error made in the duration of one phoneme would be largely compensated for in the duration of the following phoneme, which finishes at the originally planned time, despite the fact that it started late. This may be taken to imply that these two phonemes are temporally programmed as one articulatory unit and not as two separate phonemes.

Lehiste (op. cit.), in her pilot study on the temporal structure of monosyllabic and disyllabic words in English, analysed ten words of the type "steed", "staid", "stayed", "stead", "skid", "skit", "stay", "steady", "skiddy", and "skitty". She found as she states:

> '... in English there is a close interaction between the durations of vowels and following consonants in monosyllabic words, and between the durations of all the sounds within a monosyllabic or a disyllabic utterance.' (op. cit., p.166).

Lehiste (op. cit.) comes to the following conclusion:

> 'This seems to provide some independent phonetic evidence for the existence of phonological words, which I would like to define as the domain over which such temporal compensation takes place.' (ibid).

The hypothesis of temporal compensation was first suggested by Kozhevnikov & Chistovich (1967) to interpret the acoustic duration of vowels preceding voiced versus voiceless consonant.

They analysed minimal pairs of Russian words differing from each other in the consonant located in the intervocalic position in the middle of the word of the type "dobit", "dopit". The intervocalic consonant was selected according to voicing, manner of articulation and place of articulation of the consonant. They assumed that if the rhythmic programme of both words was the same, the interval between the initial and final consonants would also be the same and as they state:

> 'The difference in the interval of the intervocalic consonants (the closure for "p" should be longer than the closure for "b") should be accompanied by a compensating change of the duration of the adjacent vowel.' (op. cit., p.106).

Their results did not totally confirm their assumption because as they state:

> 'Only in the case when the words differed from each other in the voiceless or voiced nature of the consonant was there the assumed effect of the compensation of differences in the duration of the adjacent vowels.' (op. cit., p.107).

Similar findings have been obtained by Slis & Cohen (1969). In a stylised synthesis of the temporal organization of VCV context they found that a temporal compensation can be shown to occur in Dutch. They state:

> 'When the mean difference in duration of the preceding vowels and that of the silent intervals[1] are compared they seem to balance one another; this means that adding the duration of vowels and silent intervals of voiced and voiceless plosives in similar contexts would give equal values.' (op. cit., p.139).

Slis (1970) reports measurements on Dutch words of the type /bəcæp/, /cap/, /bacə/ and /bacə/ in which /c/ stands for /p/, /b/ or /m/; he found, as he states:

> '... the interval during which the lips are closed in embedded /p/ is always longer (15 - 20 ms) than embedded /b/ and /m/; with initial /p/, /b/ and /m/ no such difference in lip closure duration is observed. The total word duration proved to be independent of the voice or nasal character of the embedded consonant. Consequently, difference in duration of lip closure in embedded /p/, /b/ and /m/ are compensated by differences in duration of the other speech sounds; in words of the type /bvcə / (in which v = /a/ or /ɑ/), the

(1) Silent interval stands for closure time.

> differences in lip closure duration of embedded /c/ are mainly compensated by differences in duration of the vowel.' (op. cit., p.201-202).

Chen (op. cit.) in a cross-linguistic study of vowel duration as a function of the voicing of the consonantal environment found that, in all the test languages viz; English, French, Russian and Korean, the longer the closure time for voiceless consonant, the shorter the vowel length, and vice versa. He carried out an experiment to test the hypothesis namely:

> '... the duration per syllabic unit is relatively constant and the vowel length varies inversely as the following consonant.' (op. cit., p.146).

He analysed utterances of the type [pai $\binom{(p)}{(k)}$ (t)] assuming that:

> 'In order for the hypothesis of compensatory temporal adjustment to work, first the total duration of syllable units must be relatively constant and, secondly, the final stop must be lengthened at the expense, so to speak, of the contiguous vowel, or vice versa.' (op. cit., p.147.

The data which he obtained did not confirm this assumption. He states:

> 'If we compare [pai$\begin{matrix}(p)\\(t)\end{matrix}$] and [pai$\begin{matrix}(p)\\(k)\end{matrix}$t], there is a statistically significant variability of the order of 63 msec in the total syllabic duration. More importantly the vowel duration remains constant (exhibiting a mean difference of a mere 5 msec) while the final double stop [$\begin{matrix}(p)\\(k)\end{matrix}$t] is considerably stretched out (mean difference 73 msec).' (ibid).

Again, Chen's argument here is invalid in that in order to rule out the plausibility of the temporal compensation hypothesis, he should have analysed the temporal organization of the same data which exhibited this inverse relation between a vowel duration and a following closure duration i.e. syllables with final voiced versus voiceless consonants of the test languages, to see whether the duration per syllabic unit is the same despite the differences of vowel duration and the following closure duration of the test minimal pair. Surprisingly, he did not include such measurements in his study.

3.2.5.1 <u>Summary</u>

The temporal compensation hypothesis provides interpretations of the acoustic durational variations of vowels in terms of the compensatory temporal adjustment between the duration of a vowel and that of a following consonant i.e. the shorter duration of the vowel is compensated for by the longer duration of the following consonant closure and vice versa keeping the same originally planned time for both as one unit.

This hypothesis sheds considerable doubt on the assumption that the temporal organization of speech production occurs in terms of single phonemes temporally organized at the neurolinguistic programming stage and executed at the myodynamic (articulatory) stage in the limited time allocated for each. It seems plausible to think that such temporal organization occurs in terms of articulatory units planned at some higher (still unspecified) articulatory level each of which may comprise more than one phoneme.

3.2.6 Closure Transition

The hypothesis of closure transition was first suggested by Kozhevnikov & Chistovich (1967); it suggests that the acoustic differences of vowel duration can be attributed to the different speeds of the transition from vowel to consonantal closure. They believe that the difference in a vowel before voiced versus voiceless consonants is a side effect in the articulation of voiceless and voiced consonants. They state:

> 'The movement of the lip or tongue accomplished upon the closure of voiceless consonants are conducted with great force. Correspondingly the speed of movement in the case of voiceless consonants is greater and the moving organ reaches the final position (closure) in a lesser interval of time.' (op. cit., p.108).

They also state:

> '... voiceless consonants are characterized by longer duration of closure than the voiced stops. The hypothesis is that this is influenced by the greater strength of contraction of the muscles accomplishing the closure in the articulation of the voiceless consonants.' (op. cit., p.174).

To support this hypothesis they made photo-oscillographic recording of lip measurements(1) of the words "papa", "baba", "mama". Comparison was made between the values of duration of three sections of articulation of p, b, and m or as they state:

> '... the transition from a vowel to a

---

(1) For more details of this technique see Kozhevnikov & Chistovich (1967), Chapter 2.

> consonant (T_2), the stationary section of a consonant (T_2') and the transition from consonant to vowel (T_3).' (op. cit., p.181).

Their results confirmed the above assumption. They state:

> '... the section of closure of the consonant (stationary section T_2') proved to be the longest in the case of voiceless consonant p. However, the duration of transition from vowel to consonant (T_2) proved to be smallest in the case of p. Shortening of the duration of transition in /p/ is caused by the greater speed of movement.' (ibid).

They attribute the increase in the duration of closure of the voiceless consonant to the greater force (speed) of closure of the lips.

Similar findings have been obtained by Öhman (1967) for Swedish. In an electromyographic study on the peripheral motor commands in labial articulation Öhman (op. cit.) found as he states:

> 'In comparable contexts the onset command is usually stronger in a [p] than in a [b]. Conversely, the release command is usually stronger in a [b] than in a [p]. (op. cit., p.30).

However, he gives rather different reasons why the onset of [p] closure is earlier than that of [b] and why the closure in [p] is longer than in [b] based on the interaction between the myodynamic (articulatory) events and the aerodynamic conditions created by these events. He relies on glottographic and aerodynamic data reported by Fant (1960) which show that voiceless versus voiced consonants in Swedish are characterized by open glottis and higher intraoral pressure versus closed glottis and lower intraoral pressure respectively and states that in the case of voiceless consonants:

> '... the glottis opens up before the articulatory closure during the implosion phase is completed and remains open for about 100 msec after the articulatory phase. As a consequence of this, the intraoral pressure increases rapidly at the beginning of the closure ... the pressure impulse (time integral of pressure) acting on the closed lips from inside the mouth is much greater during the voiceless /p/ than during the voiced (b). It is, therefore, reasonable to assume that the muscular effort needed in order to prevent the lips from being blown apart by the pressure at the implosion of a /p/ should be greater than the corresponding effort for a /b/.' (ibid).

On the assumption of this anticipatory effect of the differences of muscular effort, Chen (1970) accepts the hypothesis of the closure transition hypothesis and states that the rate of transition from vowel to a voiceless consonant closure would be faster than that from vowel to a voiced consonant.

He checked this hypothesis by means of a photoelectric device for tracking lip movement. Calculations of velocity and time of lip movement toward final voiced/voiceless stop were made.[(1)] He found that lip closure movement is faster for voiceless with a ratio of 0.82. The mean difference of time needed for making the voiced and voiceless bilabial stops is 27 msec; he states that this ratio matches very closely with the mean difference in vowel duration for Spanish, Korean, Russian and Norwegian (18, 28, 29 and 33 respectively) but less well for French where the mean difference is 53 msec. To support this he mentions electromygraphic data reported by Öhman (1967) where he found that the EMG peaks of the implosion of [p] are in general of 20% greater amplitude than the implosion peaks of [b].

3.2.6.1 Summary

The hypothesis of closure transition provides

---

(1) For more details of technique and calculations see Chen (1970), p.154.

interpretations of some acoustic variations of vowels in terms of rate of closure transition of the following consonants; the more articulatory effort needed to accomplish the following consonant closure, the shorter the interval of vowel to consonant closure and vice versa.

Other myodynamic events and the resulting aerodynamic conditions involved in the articulation of both the vowel and the following consonant are also considered e.g. an open glottis and higher intra-oral pressure in the case of voiceless consonants are said to be effective not in assisting and speeding up the abduction of the vocal folds and hence contributing to the shortening of the vowel as suggested by Halle & Stevens(1) but in creating greater speed of transitional interval between the vowel and the consonant closure, associated with the higher muscle activity needed to maintain the supra glottal closure against greater aerodynamic forces.

3.3 Toward the Investigation and Interpretation of Vowel Duration in I.S.A.

In Part Two of this study an acoustic investigation of some intrinsic and segmental conditioning factors of the acoustic vowel duration in I.S.A. will be made.

---

(1) See Halle & Stevens quoted in section 3.2.4, p.144.

In manner and place of articulation particular attention will be paid to the behaviour of vowel duration when a vowel is preceded and/or followed by emphatic versus non-emphatic consonants, and when it is followed by pharyngeal and glottal versus non-pharyngeal and non-glottal consonants respectively, as these particular phonetic contexts, to the best of our knowledge, have not been investigated in such detail before. The effects of stress and geminate consonants on acoustic vowel duration will be investigated, also.

The acoustic findings will be subjected later to a myodynamic and aerodynamic investigation so that we may be in a position, either to hypothesize our own interpretation for the observed acoustic data or to see how pertinent each of the already reviewed hypotheses is to our findings.

Again, we hope to be able to contribute toward the answer to the question whether the myodynamic and aerodynamic conditions responsible for the creation of the acoustic differences of vowel duration are language-specific or phonetic-universal phenomena.

P A R T T W O

EXPERIMENTAL INVESTIGATION

CHAPTER FOUR

EXPERIMENTAL ACOUSTIC INVESTIGATION OF VOWEL DURATION IN I.S.A.

4.1 Introduction and Aims

This chapter deals with the measurements of the acoustical signal of vocoids as displayed in visual patterns and the methods by which these acoustic visual patterns are analysed as measurable segments used in our phonetic analysis of vowel duration.

The phonetic terms vocoids and contoids will be used in this chapter to replace the phonological terms vowels and consonants respectively. They are used as relative terms to define boundaries between adjacent sound segments on mingograms and spectrograms in order that measurements may be made. In articulatory and acoustic terms, a vocoid has no severe obstruction of the vocal tract above the glottis and correspondingly has a visible acoustic pattern showing relatively more energy in the middle frequencies of the spectrogram than a contoid, the articulation of which entails a severe obstruction of the vocal tract.

Four experiments were conducted in the studio and laboratory of the Department of Linguistics and Phonetics, the University of Leeds. The main objective of these experiments as a whole was to investigate some aspects of the acoustic differences of vocoid duration in I.S.A. Each experiment was conducted to deal with a specific aspect and the main aims of these experiments can be specified as follows:

(i) Experiment 1 to investigate intrinsic durations of vocoids in I.S.A.

(ii) Experiment 2 to investigate durational differences of vocoids in I.S.A. which are associated with differences of voicing and manner of articulation of the preceding and/or following contoids.

(iii) Experiment 3 to investigate durational differences of vocoids in I.S.A. which are associated with different places of articulation of the vocoid itself and of the following contoid.

(iv) Experiment 4 to investigate the influence of stress and gemination on vocoid duration in I.S.A. Also, to investigate the roles of vocoid duration, fundamental frequency and intensity as acoustic correlates of stress.

All the measurements of vocoid duration were tabulated and subjected to a statistical treatment to find out the level of significance of the differences between the samples compared.

4.2 Experimental Methods

4.2.1 Selection of Material

Monosyllabic, bisyllabic and polysyllabic words were selected to investigate the above aspects of vowel duration in I.S.A. In most cases they were real words in minimal pairs, i.e. everything was kept constant except the feature being investigated.(1) In Experiment 4, however, some nearly minimal pair words were also included. A specific set was selected for each experiment and said in a carrier sentence. The carrier sentence /'ʔikitbuu-sitmar'raat/ "write (imp. plur.) - six times" was chosen. The idea behind saying the words in a carrier sentence and not in isolation can be explained as follows: we believe that saying the words in isolation results in less reliable, less consistent and less natural speech, particularly with respect to vowel duration. On the other hand, saying the words in a carrier sentence can achieve a close approximation to natural speech. Besides, a carefully selected carrier sentence permits the investigator to have a free choice of inserting any word into the gap e.g. a noun, verb, adjective ... etc. without affecting the overall intonation and main stress of the sentence. This particular carrier sentence was chosen on the basis that the

---

(1) For more details of word list see Appendix 1.

target words should be preceded by a vowel and followed by a fricative for convenience of segmentation. The vocoid/contoid distinction could be easily established on both spectrograms and mingograms, therefore, a time point taken as the initiation of the target word could be defined without difficulty. However, it was decided that the sound following the target word should be a fricative and not a vowel because no word in Arabic begins with a vowel, as it appears from the phonological system of the language, see sections 1.3.2 and 1.3.3. Furthermore, fricatives have very distinct acoustic patterns that can help a great deal in the location of a point taken as the word boundary even if the target word terminates in a contoid which is mostly the case with our material. Nasals and liquids were avoided in the vicinity of the target words due to difficulties of segmentation, though liquids appeared to be less problematic than they are in English as we shall see in 4.2.5.4.

Each word was recorded six times. In some cases, however, one token was discarded due to either instrumental failure of difficulties of segmentation. The words were written in a list in random order with dummy items at the beginning and end of each run and randomized anew in every one of the six runs. All the six runs were recorded in one recording session after being rehearsed many times to reduce the likelihood of mistakes during the recording session. The intonation, stress, tempo and the subject's overall effort and attitude were kept as constant as possible. A moderate breath was taken after the utterance of each sentence.

4.2.2 Subject's Background

The author of this study served as the subject of all the experiments involved. I was born, brought up and educated in Basrah, a city in the south of Iraq, as a native speaker of Arabic, Iraqi spoken Arabic. I started learning English at the age of twelve. I finished my primary, intermediate and secondary school in Basrah and then moved to Baghdad where I spent four years studying at the University of Baghdad, Department of Foreign Languages, College of Education at the end of which I obtained my B.A. I started teaching English soon afterwards. I am 38 now and have been abroad for three years and a half.

4.2.3 Analysis Technique

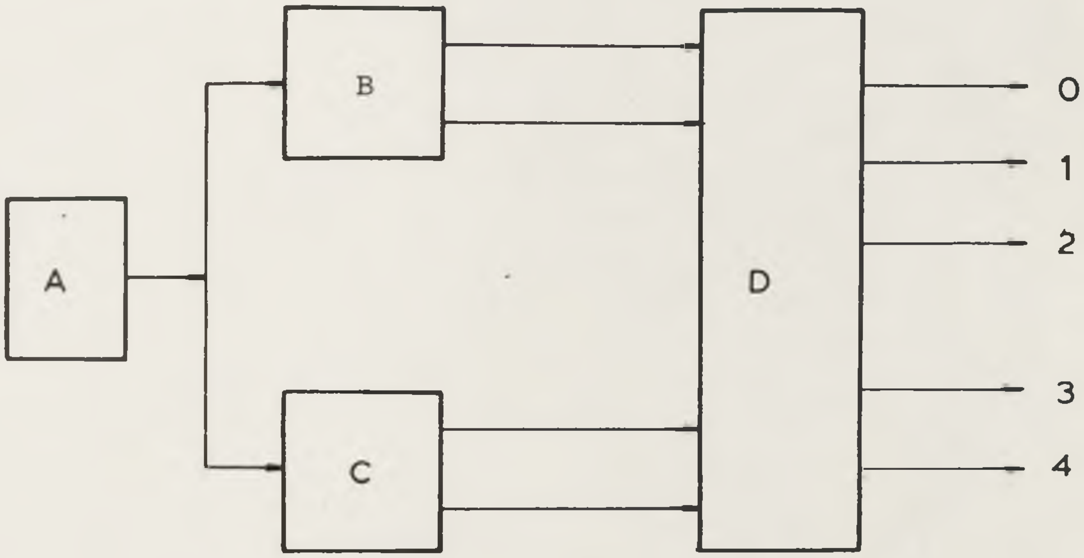
The primary apparatus used in the acoustic analysis for this study consists of Frøkjaer-Jensen's intensity meter and trans-pitch (Fo) meter and Schonander's mingograph type 803. The signal coming from a Revox tape recorder, the one on which the recording was made, is analysed by the intensity and trans-pitch (Fo) meter and displayed in the mingograph. Four channels are displayed on mingograms; channel 1 Fundamental frequency. Channel 2 Duplex oscillogram (both coming from the trans-pitch (Fo) meter). Channel 3 Intensity high pass (hereafter H.P.) filtered at 500 Hz. Channel 4 Intensity full frequency (both coming from the intensity meter). See block diagram figure 4.1.

A 700 spectrograph was used as subsidiary technique to tackle some persistent problems of segmentation encountered in this study.

4.2.4 Recording Technique and Instrumental Set-up

The recording sessions took place in the studio. A high quality magnetic tape recorder, Revox type A77 was used with an Ampex high frequency tape, type PRT 1200, at a speed of 19 cm/s and via an AKG microphone of type 190E. The distance between the microphone and the mouth was 16 cm which was kept constant through all the recording sessions. The peak sound pressure level (p.s.l.) at the microphone varied from 60 to 62 dB before recording sessions and from 61 to 63 dB after recording sessions. It was measured by a B and K portable sound level meter. The Revox settings were: record level volume 7, v.u peak intensity reading -5 dB, recording characteristic NAB and the track used ch.1

Fig. 4.1 Block diagram of the instrumental set-up for the mingogram used in the acoustic experiments of this study.



A = Revox tape recorder
B = Trans-pitch (Fo) meter
C = Intensity meter
D = Mingograph

0, 1, 2, 3 and 4 represent the output channels on the mingograms, where:

Ch.0 = Timer
Ch.1 = Fundamental frequency
Ch.2 = Duplex Oscillogram
Ch.3 = Intensity H.P. filtered at 500 Hz
Ch.4 = Intensity full frequency

mono. Before recording the speech material a 1 kHz reference tone was recorded onto the same tape for three seconds after the output control of the oscillator (Macronic Wide Range R.C. Oscillator) had been adjusted to give a v.u. meter reading of -4 dB on the tape recorder.

After recording sessions the tape was played back and an auditory analysis of the recorded material was made. Some tokens were rejected after having been found unnatural. Accordingly some runs had to be recorded again keeping the same recording technique and setting. Whenever another recording session was needed the speaker had to listen to his own recording from the previous session very carefully to get a close approximation to it. The 1 kHz reference tone was used to recapture the conditions used previously.

Once the recorded material had been found suitable for instrumental analysis, the tape was played back on the same Revox tape recorder in the laboratory. The output from the Revox was fed into the intensity and trans-pitch (Fo)meters and mingograms with four traces besides the timer trace (see section 4.2.3 and figure 4.1) were made. The output of the Revox was 8+. The input to the trans-pitch (Fo) meter was set at 12 O'clock. The low pass filter was at 150 Hz and the high pass filter was out (not used). The male setting was used and set at zero line full counter clockwise. The Duplex oscillogram on the trans-pitch (Fo) meter was set at 25 dB. The smoothing time was 10 msec and the scale was at log. The mingograph speed was at 128.5 mm/s which almost exactly corresponds (as well as we could match) (see section 4.2.6.1) to the time base on the 700 spectrograms. The 500 Ω input to the trans-pitch (Fo) meter was used. The mingograph output displayed on mingograms was according to the following setting:

ch.1 at 7¼, ch.2 at 8½, ch.3 at 7, ch.4 at 7.

Synchronization of channels was made immediately before each set and calibrations of intensity and Fo were made immediately after each set was analysed.

When broad-band spectrograms for the same tokens were needed the following procedure was followed:

(i) The input to the spectrograph was recorded at -odB on the v.u. meter for the reference tone.

(ii) The input level of the spectrograph was set at 4¾.

(iii) The output of the Revox was set at 8+ ch.1 NAB characteristic and left/right balance was set at 12 o'clock.

(iv) The scan level of the spectrograph was always set at 1 so that v.u. was zero for the strongest tokens which would, therefore, be taken as a standard for the rest of the recorded tokens. The objective behind this procedure was to arrive at a method of segmentation of the intensity traces which would be consistent with segmentation of the same items on spectrograms.

4.2.5 Segmentation Criteria

4.2.5.1 A Critical Survey

Vocoid duration is one aspect of the complex acoustical patterns of speech sounds and the problem of segmenting speech into successive phonetic units has been one of the major problems facing acousticians and phoneticians. This is largely because of the fact mentioned by Peterson (1955, p.418) who states:

> "The acoustical signal does not show a simple one-to-one correspondence with the physiological mechanism."

Fant (1960, p.22) states:

> "The number of such successive acoustic units of a speech utterance is generally greater than the number of signs in a phonetic or phonemic transcription."

Phonemic or phonetic transcription may serve as an adequate basis for a general linguistic analysis but they are by no means an adequate manifestation of the many concurrent sound features comprising a speech sound. A voiceless aspirated plosive for instance, as mentioned by Fant (1958, p.307):

> "... may be composed of a maximum of 4 segments; stop gap + explosion + frication + aspiration."

Fant also believes that the above information,

> "... cannot always be derived from the spectrographic data." (ibid).

It is often difficult to draw a definite boundary to separate speech segments from one another when we attempt to break down the speech continuum. Fant (1960, p.23) states:

> "There are as a rule a larger number of sound segments than phonemes in any utterance."

In most of the previous studies on vocoid duration spectrographic data provided the primary segmentation criteria for the measurement of a vocalic duration. Nevertheless, many problems are still being faced by phoneticians as to how to determine the segment boundaries for certain speech sounds on spectrograms. Some of these problems as seen by Peterson and Lehiste (1960) can be reviewed as follows:

(i) Initial Plosives. Besides the controversy whether or not to include aspiration with the duration of the vocalic segment following a voiceless aspirated plosive they were also faced with the difficulty concerning a concentration of fricative energy in the regions of higher formants through the aspriation period. They state:

> "... it was difficult to decide whether at a given moment the pattern in those formants represented breathy phonation or modulated fricative energy." (op. cit., p.694).

In the case of initial voiced plosives, the period of aspiration was absent, but, as they state:

> "... the period of frication following the spike was usually more prominent than in the case of voiceless plosives. The measurements were again made from the centre of the spike, so that the frication period was included in the duration of the vowel." (ibid).

(ii) Initial and Final Nasals. In the measurements of vocoid duration preceded and followed by nasals, initial nasals offered no difficulty. In the case of two speakers, however, the vowels were nasalized considerably. On this difficulty they state:

> "... nasalization of vowels obscured the transition from the syllable nucleus to the final nasal consonant on the broad-band spectrograms.' (op. cit., p.695).

Approximate boundaries were located on narrow band spectrograms for these speakers where, as they say: "... there was a sudden change in the relative marking of the various harmonics." (ibid).

(iii) Initial and Final Fricatives. After initial voiceless fricatives and initial /h/ the boundary was determined by the onset of voicing in the region of the first formant. Formant movements here were not adequate indications of the points of transition because, as they state:

> "... there was a "breathy" quality for initial /h/ on the broad-band spectrogram after the onset of voicing (noise pattern superimposed upon a rather clear formant pattern)." (op. cit., p.696).

In this case they relied on the intensity curves on mingograms which "... provided a valuable additional reference" (ibid) (our emphasis), and, "a relatively unambiguous cue." (ibid) (our emphasis).

In deciding a definite boundary preceding a final voiced fricative the difficulty was even greater because the transition between vowel and consonant appeared rather gradual. In this case they had recourse to the intensity curve again where, "... the onset of high-frequency energy inthe case of /z/ and /ʒ/ provided a clear boundary." (op. cit., p.697). The boundaries preceding final /v/ and /ð/ could also be recognized, "... by the rapid decrease of energy that could usually be detected on the intensity curves." (ibid).

(iv) Final /l/ and /r/. It was very difficult for them to decide a definite boundary for /l/ and /r/ and a preceding vowel because as they state:

> "Very often the formant movements were quite smooth and the establishment of a boundary on the basis of broad-band spectrograms was questionable." (op. cit., p.678).

They also had recourse to intensity curves on mingograms which, "... were helpful in instances where the vowel had an intrinsic energy considerably different from that of /l/ or /r/." (ibid) (our emphasis).

Fant (1958, p.285) believes that, "The Sonograph has some imperfections such as inadequate portrayal of very weak sounds.". He evaluates the contribution of the mingograph to the processing of phonetic data and states:

> "It is probable that these techniques will

> change the general attitude toward phonetic mass investigation, especially with regard to the study of prosodic categories such as sentence stress and intonation and word accent or any other phonetic category that is related to duration, intensity and fundamental pitch of the speech wave."
> (op. cit., p.328).

Fischer-Jørgensen (1964) used Frøkjaer-Jensen's trans-pitch meter and intensity meter as primary technique for the measurements of vocoid duration. The signal from the tape was passed through a pitch-meter and an intensity-meter, and recorded on a 4-channel mingograph.

Fischer-Jørgensen (op. cit., p.182) chose as the basis for her segmentation criteria the "Logarithmic intensity curve, sharply high-pass filtered at 315 cps for the female, and at 250 for the male voices." The points in time where the intensity curve rises and goes down abruptly were taken as the onset and offset of vocoid duration respectively. Fischer-Jørgensen (op. cit.), however, did not establish a threshold value for the intensity trace where more consistent, though still arbitrary, points in time could be taken for the measurements of vocoid duration (see the following section). Furthermore, she states that spectrograms were used in cases of doubt to help in the identification of segment boundaries, but she does not mention whether there was any match up between the intensity curves and the corresponding pattern on spectrograms to enable us to make reliable and consistent comparisons with the measurements of previous studies done mainly on spectrograms.

Other segmentation criteria have also been used. Margaret A. Naeser (1970) presented segmentation criteria for the measurement of vocoid duration on duplex oscillograms, claming that the use of duplex oscillogram, rather than sound spectrograms:

> "... permits faster production (real time) at less expense (adding that machine paper may be used). The speech signal can be more spread out on a duplex oscillogram than on a spectrogram, increasing ease of segmentation; duplex oscillograms provide an equally clear display for speech of high- or low-fundamental frequency." (op. cit., p.ix).

4.2.5.2 <u>Our Segmentation Criteria</u>

In this study we present segmentation criteria for the measurement of vocoid duration based on intensity curves on mingograms. These criteria can be explained as follows:

(i) For details of the instrumental set-up see section 4.2.4.

(ii) The intensity curve chosen for this purpose is that of intensity H.P. filtered at 500 Hz.

(iii) A threshold value of intensity (H.P. filtered at 500 Hz) was arbitrarily set at 26 dB above the baseline i.e. background noise level, which was maintained throughout the experimental study.

(iv) Duration measurements were made between points in time where the intensity trace crosses the threshold value (26 dB) of intensity (H.P. filtered at 500 Hz). See figure 4.2.

(v) In cases where the intensity trace (H.P. filtered at 500 Hz) does not fall below the threshold value (26 dB) the following criteria are used:

(a) The points where sudden changes of slope occur on the intensity trace are taken to represent major points of transition in the activities of the vocal tract and thus they correspond to similar patterns on spectrograms e.g. a sudden and steady rise in the intensity trace to a higher level corresponds to the beginning of the strongly marked patterns for higher formants that characterize vocoids on spectrograms, and both correspond to the onset of the characteristic energy of vocoids. See figure 4.3.

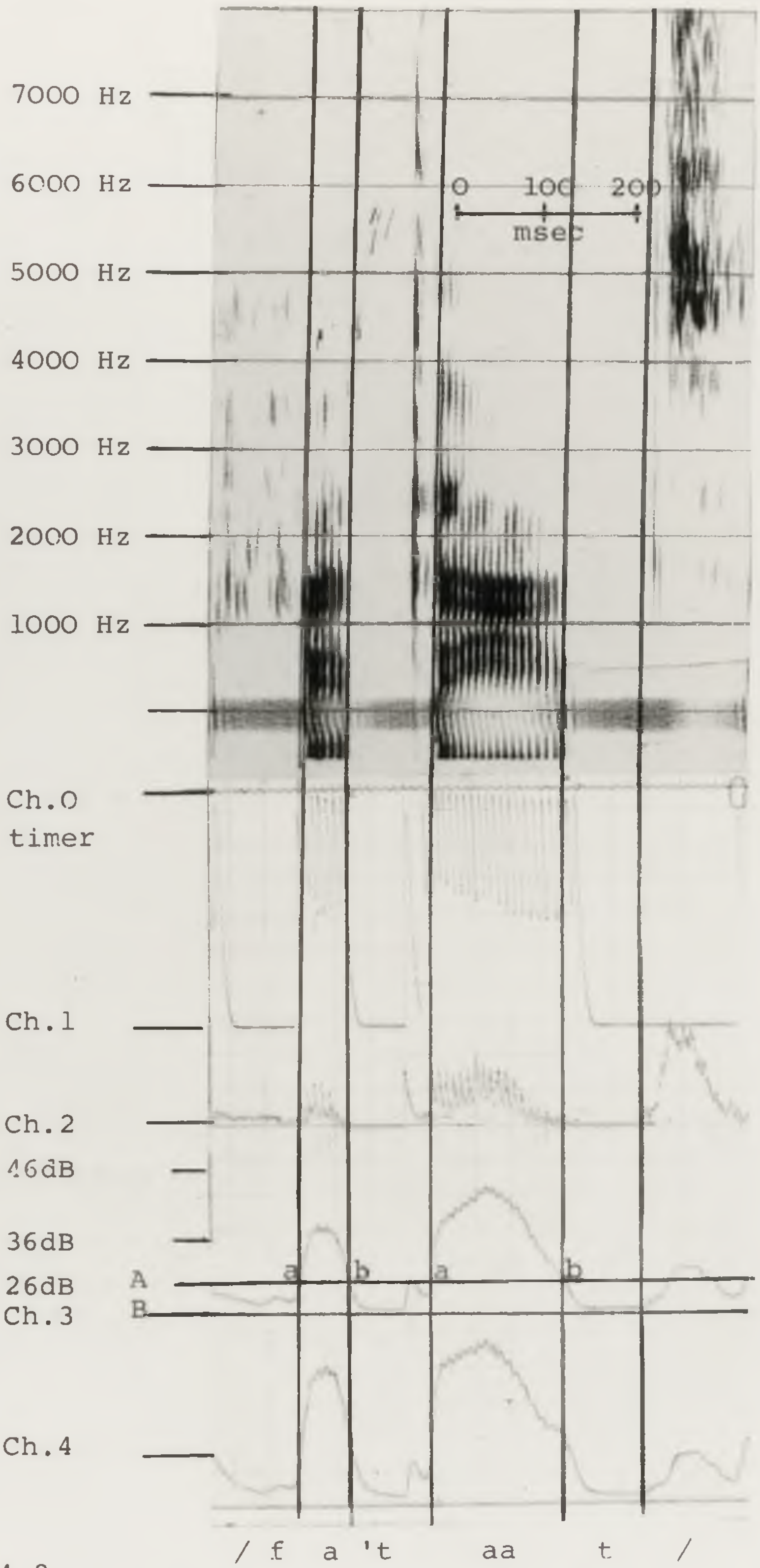


Fig. 4.2
Spectrogram and Mingogram of the word /fa'taat/ "girl" in the carrier sentence /'ʔikitbuɣ— sit mar'raat/. The Mingogram displays the following channels:
Ch.1 = F_o.
Ch.2 = Duplex Oscillogram.
Ch.3 = Intensity H.P. filtered at 500 Hz.
Ch.4 = Intensity full frequency.
A = Threshhold value of intensity arbitrarily set at 26dB above the baseline (background noise level).
B = Baseline of Intensity trace. H.P. filtered at 500 Hz.
a & b represent points in time where this intensity trace crosses the threshhold value of 26dB. The distance between these two points is taken to represent the vocoid duration of the two vocalic segments [a] and [aa]. In this example their durations are 55 msec and 150 msec respectively.

(b) Once these points were identified, vertical lines were drawn from them down to the threshold value of intensity. Points where these vertical lines cut the threshold value of intensity were taken to be the beginning and end of a vocoid for the purpose of duration measurements. See figure 4.4.

Our choice of intensity curve and particularly H.P. filtered at 500 Hz as well as the setting of threshold value of intensity at 26 dB is based on the following assumptions:

(i) Our choice of intensity curve as the basis of our segmentation criteria stems from the fact stated by Sacia (1926, p.629) that: "Vowel sounds carry by far the most of the power and energy of speech." (our emphasis) and that consonants are relatively inferior to them in this respect. If we define sound intensity as: "the sound energy transmitted per unit of time by a unit area of the wave front and in the direction of propagation of the wave." (Fletcher, 1934, p.60) (our emphasis), and that: "intensity is proportional to the square of rms amplitude and also to the square of frequency." (Scully, 1973, p.3) (our emphasis), we consequently assume that all vocoids are characterized by the greatest amplitude and thus their boundaries, as stated by Chen (1970, p.132): "ought to be specifiable in terms of the change in source intensity."

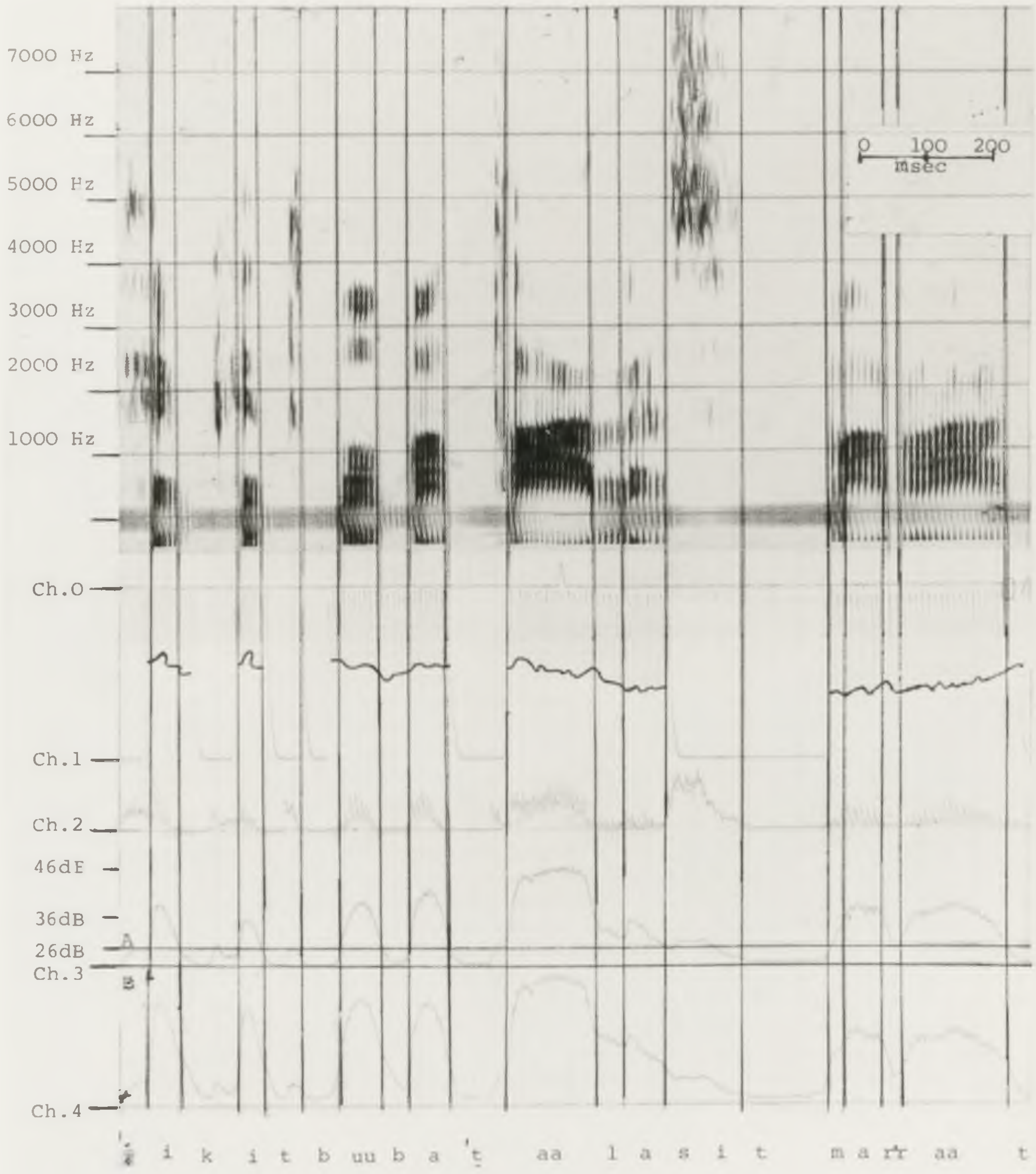


Fig. 4.3

Spectrogram and Mingogram of the word /ba'taala/ "unemployment" in the carrier sentence /ʔikitbuu— sit mar̄'raat/.
Traces are the same as in Fig. 4.2.
Notice the changes of slope occurring on the Intensity curves and the corresponding patterns on the spectrogram.

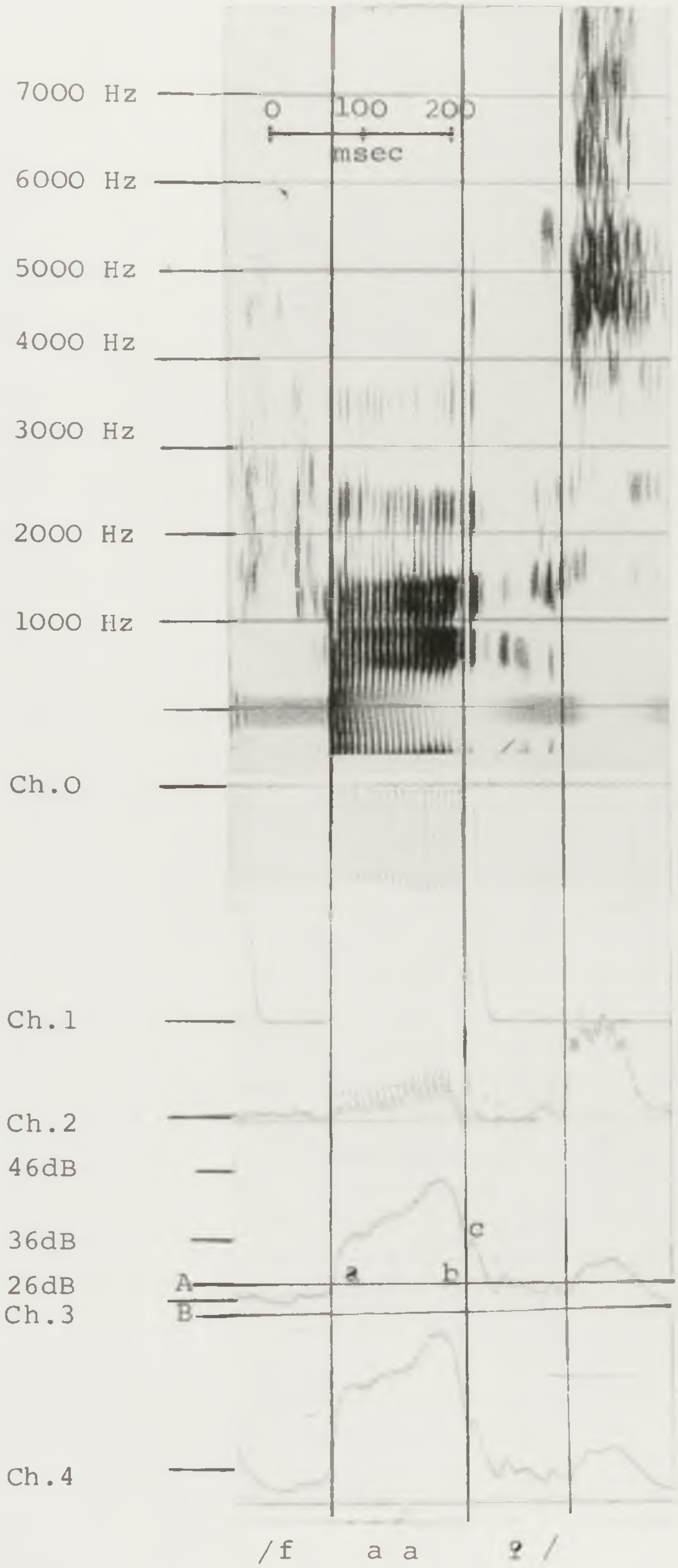


Fig. 4.4

Spectrogram and mingogram of the word /faaʕ/ "the letter f" in the carrier sentence /'ʔikitbuʊ- sit mar'raat/. Traces are the same as in figures 4.2 and 4.3. A and B as well as a and b are the same as in the previous figures. C represents the point in time where a sudden change of slope occurs which can be taken as a shift of pattern in the intensity curve for cases in which the intensity curve does not go below the threshhold. In this case a vertical line was drawn between (c) and (b) to help in measuring the vocalic segment [aa].

(ii) Our choice of intensity trace (H.P. filtered at 500 Hz) is due to our wish to eliminate most of the energy below 500 Hz. This is because some voiced contoids may show some energy in frequency regions below 500 Hz which might be merged in the intensity curve representing vocoid energy. This corresponds to the "voice bar" which appears in the region of 500 Hz or lower on spectrograms as part of the sound structure of the preceding and/or following voiced contoids.

(iii) Two attempts were made to set a threshold value of intensity (H.P. filtered at 500 Hz) one at 20 dB and another at 30 dB and both were found to be unsuitable. A threshold value was then set at 26 dB and found to be convenient in the sense that it allows duration measurements of unstressed vocoids or vocoids having low intensity the peak of which might not go as high as 30 dB. Besides, it allows almost perfect match of vocoid duration on mingograms (intensity trace H.P. filtered at 500 Hz) with those on spectrograms. See tables 4.1.A, 4.2.A, 4.1.B, 4.2.B.

(iv) One of the main advantages of the use of intensity curves is that it allows duration measurements of unstressed short vowels of very short duration which are very difficult to segment on spectrograms. Besides, it saves time, effort and expense. It also provides a relatively easier segmentation (cf. problems of segmentation, Peterson and Lehiste (1960)).

4.2.5.3 The Question of Reliability and Consistency of Our Segmentation Criteria

It is believed that our segmentation criteria will provide internal consistency of duration measurements throughout this study. There was a possibility, however, that our duration measurements on mingograms would not match those on spectrograms and these measurements, therefore, would be incompatible when compared with those achieved in similar previous or future work. The argument behind this possibility can be explained as follows:

On a spectrogram, in general, F1 falls in frequency near a plosive or indeed any contoid because in general narrowing the vocal tract in most places lowers F1. This may not be true in the case of Arabic emphatic and pharyngeal contoids in which the articulation entails a constriction at the rear section of the vocal tract i.e. the pharyngeal region. For a constriction in this region of the vocal tract, F1 does not go down in frequency but is predicted to go up toward F2 unless there is a lip rounding. This is why F1 and F2 during the articulation of the emphatics are close to each other whereas they are distinctively apart during the articulation of the non-emphatics. See figures 4.5 and 4.6.

Since the intensity H.P. filtered at 500 Hz includes nearly everything on spectrograms above 500 Hz but much less from below 500 Hz i.e. it does not include much of a contribution from F1 during the closing phase for most plosives and fricatives, the intensity will, therefore, fall below the 26 dB threshhold roughly where F2 energy becomes suddenly weak. Consequently, the two methods of segmentation i.e. (i) intensity H.P. filtered at 500 Hz down below threshhold, (ii) F2 suddenly weak on spectrogram, should agree pretty well during the articulation of the non-emphatic contoids.

During the articulation of the emphatic contoids, on the other hand, if F1 does not fall below 500 Hz in this boundary region, it may contribute noticeably to the intensity H.P. 500 Hz trace. In this case the intensity trace might not reflect the strength of F2 but of F2 and F1. Thus we might have a poorer agreement here between the two methods of segmentation.

It follows from this argument that if segmentations on spectrograms are made at the F2 level, segmentations on mingograms might show a slightly long vocoid when an emphatic contoid follows.

Accordingly, the reliability of our segmentation criteria was checked by the following procedure.

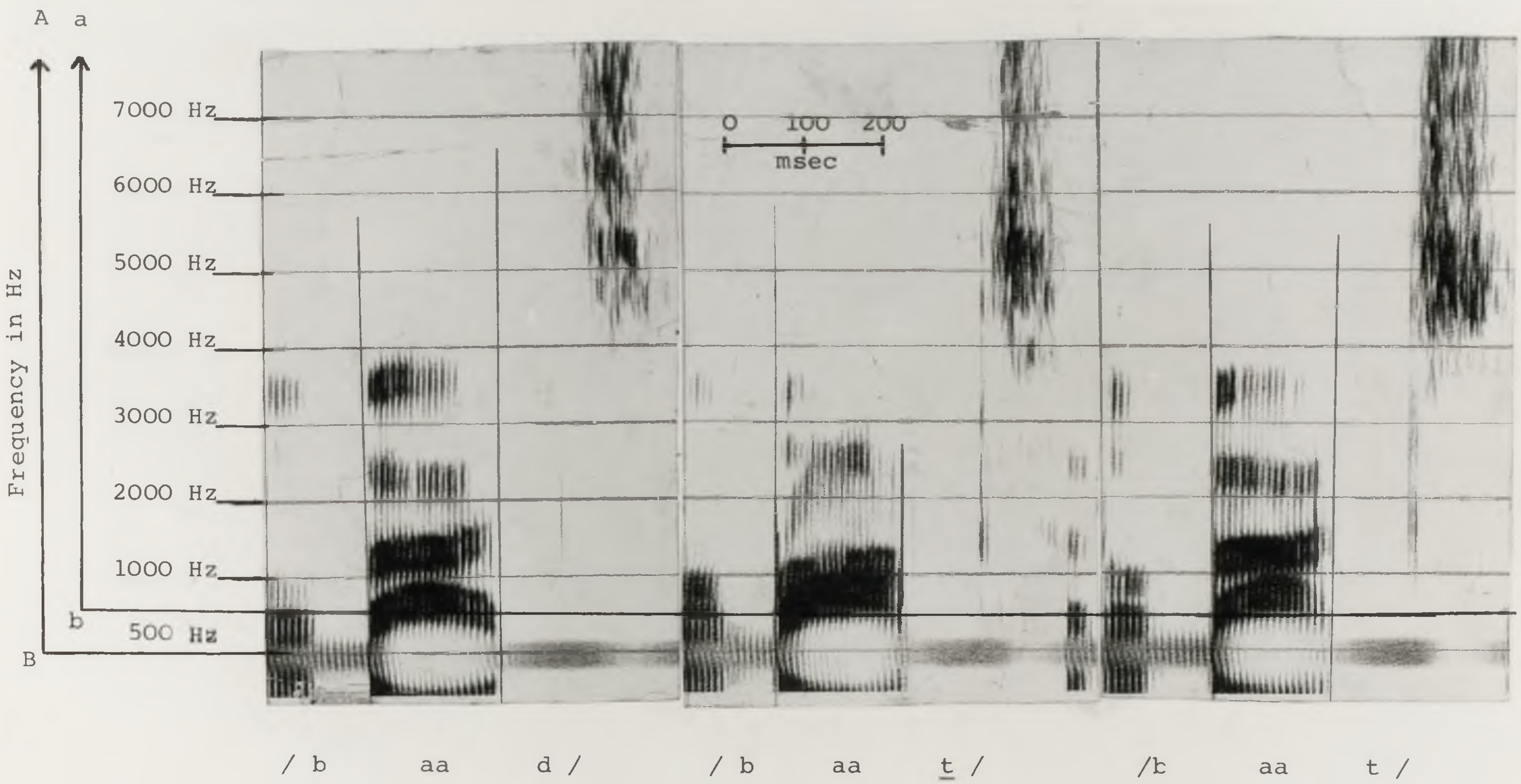
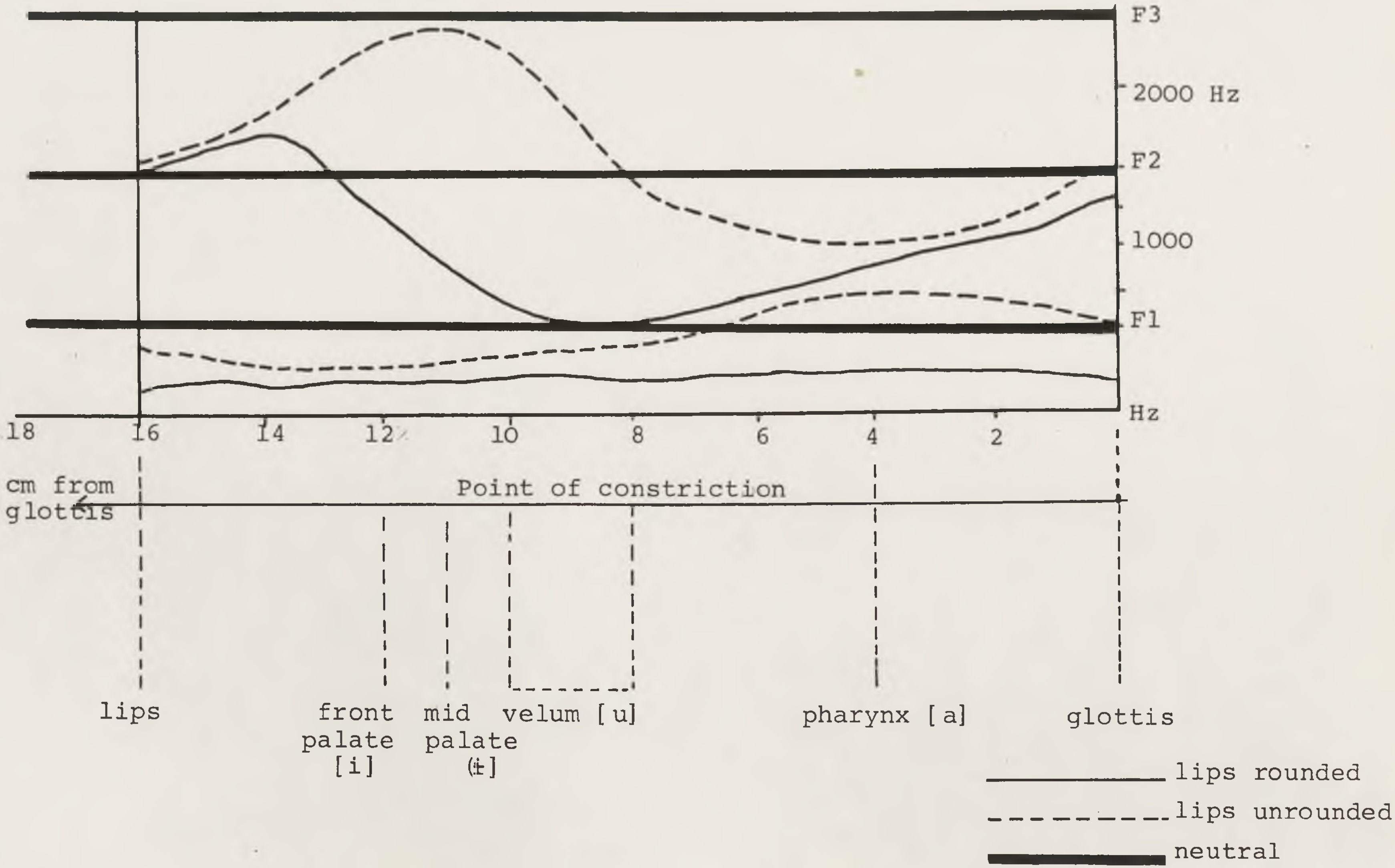


Fig. 4.5 Spectrograms of the words /baad/ "worn out", /baat/"armpit" and /baat/ "spent the night" each in the carrier sentence, /'ʔikitbuu — sit mar'raat/.
A - B represents the domain of intensity full frequency as displayed on mingograms Ch.4.
a - b represents the domain of intensity H.P. filtered at 500 Hz as displayed on mingograms Ch.3.

Fig. 4.6* F. pattern diagram for average man's vocal tract F1 and F2 movements for vowels with a narrow tongue constriction. (*Based on Fant (1960, p.82)(Simplified)).



Spectrograms of six words were made with six tokens for each. The words were chosen to show whether in segmenting on spectrogram the emphatic versus non-emphatic contrast shows any divergence when compared to the same context segmented on intensity traces H.P. filtered at 500 Hz with the threshold value set at 26 dB. F2 level was taken as the indicator of vocoid energy. The major criteria that are used in segmentation on spectrograms are the same as those suggested by Peterson and Lehiste (1960). The frication and aspiration following voiced and voiceless plosives are excluded from the target vocoid duration on spectrograms as well as on mingograms throughout this study.

Duration measurements made for the target vocoid duration in msec on spectrograms were compared with the duration measurements in msec for the same vocoid on mingograms. Tables 4.1.A, 4.2.A, 4.1.B, 4.2.B as well as figures 4.2, 4.3, 4.4 show an almost perfect match of our segmentation criteria on mingograms, Intensity H.P. filtered at 500 Hz where the threshold value was set at 26 dB with the criteria of segmentation on spectrograms followed by Peterson and Lehiste (1960).

We may, consequently, conclude that duration measurements based on our segmentation criteria may undoubtedly be regarded as externally as well as internally consistent when our results are compared with those obtained in previous or future work.

Duration measurements in msec of the underlined segments measured on a mingogram trace of intensity H.P. filtered at 500 Hz where threshhold value of intensity is arbitrarily set at 26 dB above the base line (displayed on ch.3).

tokens	baat	baat	baad
1	165	150	170
2	160	150	170
3	155	150	165
4	165	155	180
5	160	150	160
6	155	150	155
Aver.	160	150	165

Table 4.1.A[(1)]

tokens	bat	bat	bad
1	80	75	80
2	80	80	75
3	95	80	85
4	85	80	85
5	85	70	85
6	80	70	85
Aver.	85	75	85

Table 4.2.A

Duration measurements in msec of the underlined segments measured on spectrograms taking F2 level as the criterion for vocoid energy.

tokens	baat	baat	baad
1	165	150	165
2	160	145	165
3	155	145	160
4	165	150	175
5	160	150	160
6	155	150	155
Aver.	160	150	165

Table 4.1.B

tokens	bat	bat	bad
1	75	70	80
2	80	75	75
3	90	80	85
4	85	80	85
5	85	70	85
6	85	70	85
Aver.	85	75	85

Table 4.2.B

(1) Note that the A and the corresponding B tables are for the same recorded items.

4.2.5.4 Problems of Segmentation Encountered in this Study

The above argument is by no means intended to imply that all segmentation problems were overcome by employing such criteria. One should always remember the fact mentioned by Peterson and Lehiste (op. cit., p.694) that: "Segmentation has long been and continues to be a major problem in speech analysis." (our emphasis). Our criteria may only provide partial solutions for some of these problems which have been reported in every language subjected to instrumental analysis.

Besides spectrograms, a duplex oscillogram displayed on mingograms ch.2 was also used and both techniques were very helpful in giving adequate cues in the establishment of segment boundaries in cases of doubt.

The easiest boundaries to establish were those of vocoids preceded and/or followed by voiced and voiceless plosives where the trace of intensity H.P. filtered at 500 Hz showed a sudden rise from the base line to higher levels. In the cases of frication and aspiration the pattern could be easily distinguished from that of the following vocoid and often was cut below the threshold value.

Boundaries of vocoids preceded and/or followed by voiceless fricatives such as [s̲], [s], [ʃ] and [x] were not difficult to establish in cases where the shift of pattern occurs above the threshold value.

Voiced fricatives following and/or preceding the target vocoid presented a considerable difficulty, particularly when the shift of pattern occurs above the threshhold value or in cases where their pattern is merged with that for the vocoid in the intensity curve. In such cases duplex oscillograms where decrease of vocoid energy was marked by shift of pattern i.e. a sudden descent to the base line followed by a gradual but clear rise, as well as F2 level on spectrograms provided valuable clues and were used as alternative criteria where necessary.

Open vowels preceded and/or followed by nasals or liquids and approximants such as [l] and [r] were not difficult to segment. This is largely due to the fact that open vowels usually have stronger intrinsic energy and, therefore, show distinctively higher intensity level than the following or preceding nasals or liquids, though it was difficult sometimes to draw a segment boundary in cases when the open vowel was unstressed. The difficulty was even greater when the vowel was close (stressed and unstressed), as close vowels have weaker intrinsic energy than open vowels and therefore show relatively low intensity very difficult to distinguish from that of a preceding and/or following nasal or liquid. In such cases the spectrogram provides invaluable clues; a change in formant pattern from a steady movement to rather less steady and less dark pattern or vice versa was taken to represent a boundary between a vocoid and a following or preceding liquid; a sudden change in formant pattern from steady pattern to rapid or glide movement or from sudden off glide movement to a steady pattern was taken as a segment boundary between a vocoid and a following nasal or a nasal and a following vocoid respectively.

It has also been confirmed in this study that "... transition between sounds with the same manner of articulation, e.g. between two vowels are much more difficult to determine." (Lehiste,1970, p.13) than those between sounds with different manners of articulation. Fant (1973, p.29) states:

> "Segment boundaries are associated with changes in the manner of production (voiced/voiceless, fricative/non-fricative, nasal/non-nasal, etc) whereas the place of articulation determines acoustic patterns that vary more or less continuously within and across segment boundaries."

4.2.6 Measurements

4.2.6.1 Duration Measurements

Vocoid durations are measured and tabulated in msec throughout this study. Duration measurements were made on mingograms. The time scale on the mingograph was adjusted to match that on the spectrograph i.e. the two sets of apparatus were matched. This scale is almost exactly 5 inches representing 1 second, but the exact time scale of 128.5 mm representing 1 second was used.

The scale on both spectrogram and mingogram was checked and measured by the following procedure:

Square waves and sine waves with a fundamental frequency of 100 Hz were generated by an Advance Oscillator. The frequencies were checked by means of a Venner Timer and recorded on a Revox A77 and were played back on the same Revox into the mingograph (straight from the tape recorder). The cycles of the square wave as well as those of the sine wave were counted and each was found to be almost exactly 100 in 1 second time interval on the mingogram.

The same frequencies were played back on the same Revox and copied onto the Crown recorder on the 700 spectrograph. Two spectrograms were made, one for a square wave and another for a sine wave. The distance for 100 cycles was measured for both. Cycles of square and sine waves of the same distance were counted and each wave was found to comprise 100 cycles for the distance representing 1 second in time on the spectrogram.

Distance for 1 second in time on the mingograph timer as well as on a spectrogram was checked and measured as accurately as possible with a Rabone Chesterman ruler No.64R and found to be in almost perfect agreement.

4.2.6.2 Fo Measurements

Measurements of Fo values for vocoids were made in Hz on ch.1 on mingograms by means of a scale from a calibration provided by the trans-pitch (Fo) meter. Fo was measured at mid-vocoid, vocoid boundaries having been determined from ch.3. (See section 4.2.5.2).

In figure 4.7 the point a represents the middle of the vocalic segment [uu], b represents the corresponding point in time to the middle of the vocalic segment on the Fo trace. The distance between b and c was taken to represent Fo of this vocalic segment, using the Fo calibration scales.

4.2.6.3 Intensity Measurements

Intensity measurements were made for vocoids in dB by means of a scale from the calibration provided by the intensity meter on ch.4 i.e. intensity full frequency tracing which includes all the frequency regions. The peak intensity was taken as the point in time where the highest point of the intensity curve was reached in each vocalic segment i.e. the strongest portion of the target vocalic segment. A corresponding

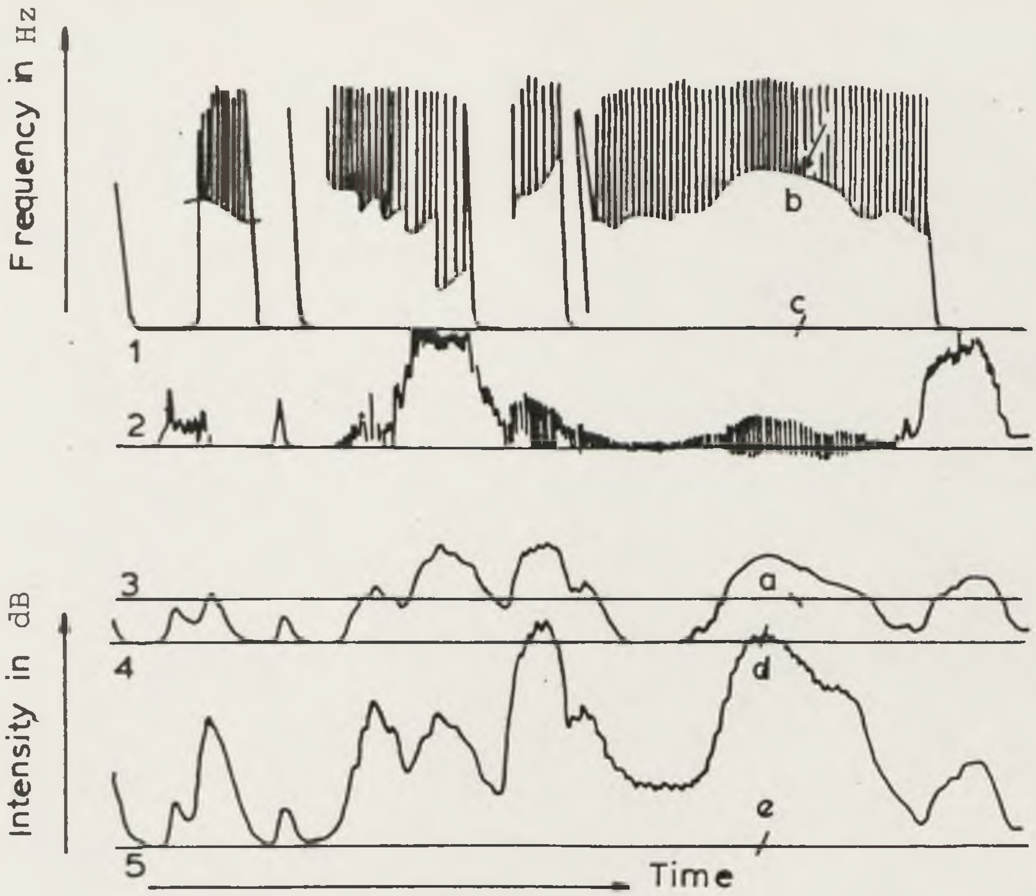


Fig. 4.7

Mingogram of the word /ʃir'buu/ in the carrier sentence /ʔikitbuu- sit mar'raat/ showing where Fo and intensity values are measured for the vocalic segment [uu].

1. Baseline of Fo trace.
2. Baseline of Duplex Oscillogram.
3. Threshhold value of 26 dB.
4. Baseline of intensity trace (H.P. filtered at 500 Hz).
5. Baseline of Intensity full frequency trace.

(a) The point in time taken to represent the middle of the vocalic segment for [uu].
(b) Fo value at the middle of the vocoid.
(d) Peak intensity on the full frequency intensity trace, within the vocoid segment.

point in time was established on the base line of the Intensity full frequency trace. In figure 4.7 the distance between d and e is taken to represent the intensity of the target vocalic segment using the intensity calibration scales.

However, there were cases where the peak intensity of certain vocoids went further than 50 dB which is the highest point read off the scale from the calibration. In such cases the 1 KHz tone which was recorded on the Revox before recording the speech material was boosted by raising the output gain setting to the level required for the highest peak. The signal then was fed into an attenuator and into the intensity meter and then displayed on mingogram -

Revox —1 kHz→ Attenuator → Intensity → Mingo

The calibration range of the intensity trace was extended upwards, using the 1 kHz reference tone recorded on the tape. An attenuator was used to give known increases above the 50 dB level.

4.2.7 Mann-Witney U Test and Level of Significance

All the acoustic measurements of vocoids (duration, Fo and intensity) made in this study were subjected to a statistical test in order to infer whether, in terms of probability, the observed durational differences of vocoids in two independent samples, say /baat/ and /baad/, '... signify that the populations sampled are themselves really different.' (Siegel, 1956, p.2), or whether these differences, '... occur simply because of the operations of chance.' (ibid). In behavioural sciences to reach such a statistical inference the researcher should specify a null hypothesis (Ho) i.e. '... a hypothesis with no differences. It is usually formulated for the express purpose of being rejected.' (ibid). If this hypothesis is rejected the alternative hypothesis (H1) may be accepted.

> 'The alternative hypothesis is the operational statement of the experiment's research hypothesis. The research hypothesis is the prediction derived from the theory under test.' (ibid)

If we assume that each research hypothesis of this study predicts differences in the acoustic duration of vocoids due to the influence of the phonetic contexts mentioned in section 4.1 which were selected to test the theory of vowel duration surveyed in Chapter Two, then we accept this hypothesis when Ho, which predicts no differences, is rejected and vice versa.

To implement such a procedure, a non-parametric statistical test was chosen, i.e.

> '... a test whose model does not specify conditions about the parameters of the population from which the sample was drawn.' (op. cit. p.31).

This choice has been largely due to the fact stated by Siegel (op. cit., p.32):

> 'If sample sizes as small as N = 6 are used, there is no alternative to using a non-parametric statistical test unless the nature of the population is known exactly.'

The non-parametric statistical test used in this study for rejecting or accepting (Ho) is the Mann-Whitney U test which is, '... one of the most powerful of the non-parametric tests'. (op. cit. p.116). This test was computerized and done on a PET microcomputer.[1] 2-tailed tests are used throughout this study. This is due to the fact that even if we have very strong previous work to suggest which direction vowel duration differences are likely to operate for particular phonetic contexts (notably when followed by voiced versus voiceless consonant), so that 1-tailed tests might be used in these cases, it is not considered good practice to mix 1- and 2-tailed tests when the difference is expected to go both directions for other phonetic contexts.

---

(1) For more details of the computer programme see Appendix 2.

As for the level of significance i.e. the probability level at which Ho is to be rejected, it has been a common practice, '... for the researcher simply to report the probability level associated with his findings, indicating that the null hypothesis may be rejected at that level.' (op. cit., p.8, footnote (1)).

Nevertheless, the reader may use his own judgement in deciding whether Ho should be rejected or not. Siegel (op. cit., p.9) states:

> 'A researcher may decide to work at the 0.05 level, but a reader may refuse to accept any finding not significant at the 0.01, 0.005 or 0.001 levels, while another reader may be interested in any finding which reaches, say, the 0.08 or 0.10 levels.'

In the light of the above statements, two levels of significance have been specified in this study for rejecting Ho. The first level is $p \leq 0.05$, a level commonly used in psychological and sociological studies, which marks the area of rejecting Ho where the difference will be described in this study as statistically very significant. The second level is $p > 0.05$ and $p \leq 0.07$ which marks another area of rejecting Ho but where the difference will be described as only statistically significant.

The limits of accuracy of measurement are not precisely known, but are probably about plus or minus 5 msec for duration, plus or minus 1 cm H_2O for pressure, plus or minus 2 L/m for airflow and plus or minus 1 dB for intensity. It is theoretically possible, therefore, that a small difference in even a single measurement could change the result of the statistical test used from "very significant" to only "significant" or even, in some cases, to "not significant". Caution should therefore be exercised in basing conclusions on such statistical results, particularly those marked in the text by the symbol †.

4.3 Results

All the measurements for each set of tokens and the U and p values for the two sets of tokens being compared as well as the average values of each set were arranged in tables. Tables were subdivided in accordance with the aims specified in section 4.1.

In the columns under U and p the reader's attention is drawn to the note that each U value has a corresponding value of p which is the probability level of significance; the smaller the number of U and its corresponding value of p the higher the level of significance i.e. the higher the probability that the two sets of data belong to two different populations. p values corresponding to U values were drawn from table J (N2 = 6) of probabilities associated with values as small as observed values of U in the Mann-Whitney U test(Siegel, 1956, p.271).

4.3.1 Intrinsic Duration

Table 4.3.1 is subdivided into two categories. The first category is subdivided into (a) and (b). In (a) the table shows that all open and centralized vowels are longer than their corresponding close front and centralized vowels and in all cases the difference is statistically very significant; the only overlapping in this category occurred in /das/ versus /dis/ where there are only two identical scores out of twelve. For this pair the difference is at less than p = 0.004 whereas the differences of all the other sets compared are at p = 0.002.

In (b) the table shows that all open back vowels are longer than their corresponding half close to half open and close back vowels and the difference is <u>statistically very significant</u> in all cases. However, some overlapping occurred as in /s̲aaɣ/ versus /s̲ooɣ/ where there are some identical scores and one overlapping score out of eleven scores for which the difference is at p = 0.03 and in /boos/ versus /buus/ where there are four identical scores out of twelve for which the difference is at p = 0.008. It is interesting to observe the overlapping that occurred between /aa/ which is an open back vowel and /oo/ which is a half close to half open back vowel. The same overlapping also occurred between /oo/ and /uu/ which is a close back vowel whereas there is no overlapping between /aa/ and /uu/ as in /s̲aaɣ/ versus /s̲uuɣ/ the difference for which is at p = 0.004. Yet, there is also no overlapping between /oo/ and /uu/ as in /s̲ooɣ/ versus /s̲uuɣ/.

In the second category the table shows that all long vowels: /aa/, /ii/ and /uu/ are longer than their counterpart short vowels: /a/, /i/ and /u/ and this difference is <u>statistically very significant</u>, being in all cases at p = 0.002 which is the highest level in

Mann-Whitney tables (2-tailed), i.e. no overlapping whatsoever occurred in any scores of the sets compared.

Figure 4.8 which corresponds to table 4.3.1 illustrates some of these findings. Differences for long versus short vowels are not included because they are all at the level p = 0.002.

Table 4.3.2 shows ratios of long vowels to short vowels according to the average values when all the consonant environments are pooled. It shows that the ratio of /aa/ to /a/ is 2, /ii/ to /i/ is 1.87 and /uu/ to /u/ is 1.62.

Figure 4.9 which corresponds to tables 4.3.1 and 4.3.2 shows in symmetrical shape and according to the average values when the consonant environments are pooled that for long vowels; /aa/ > /oo/ > /uu/ > /ii/ and for short vowels /a/ > /u/ > /i/. It also shows how the two categories of long and short vowels are distinctively apart.

Our data concerning the durational differences between open and close vowels and long and short vowels agree with those reported by House & Fairbanks (1953) in the sense that in the case of open versus close vowels vowel duration seems to be directly related to the size of mouth opening and inversely related to tongue height. Our data also, as we shall see in Chapters Five,

Table 4.3.1. Duration Measurements in msec of Vocoids According to their Intrinsic Duration

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
1. Open versus close vowels									
(a) Front and centralized vowels									
/ʕad/	100	70	80	85	100	105	90	0	0.002** (1)
/ʕid/	65	60	60	50	65	60	60		
/ʕaad/	185	195	195	220	175	205	195	0	0.002**
/ʕiid/	115	100	115	115	135	125	120		
/das/	80	70	80	110	85	85	85	0.5	less than 0.004**
/dis/	70	55	65	55	55	55	60		
/daas/	155	165	150	175	155	140	155	0	0.002**
/diis/	100	95	95	110	115	115	105		
(b) Back vowels									
/saaɣ/	185	195	210	200	185	195	195	0	0.004**
/suuɣ/	-	130	140	155	115	155	140		
/saaɣ/	185	195	210	200	185	195	195	3	0.03**
/sooɣ/	170	-	195	165	180	170	175		
/sooɣ/	170	-	195	165	180	170	175	0	0.008**
/suuɣ/	-	130	140	155	115	155	140		
/boos/	165	155	160	160	155	180	165	2	0.008**
/buus/	155	150	115	150	130	155	145		

Table 4.3.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
2. Long versus short vowels									
/ʕaad/	185	195	195	220	175	205	195	0	0.002**
/ʕad/	100	70	80	85	100	105	90		
/daas/	155	165	150	175	155	140	155	0	0.002**
/das/	80	70	80	110	85	85	85		
/ʕiid/	115	100	115	115	135	125	120	0	0.002**
/ʕid/	65	60	60	50	65	60	60		
/diis/	100	95	95	110	115	115	105	0	0.002**
/dis/	70	55	65	55	55	55	60		
/ʕuud/	110	135	115	150	115	135	125	0	0.002**
/ʕud/	65	70	85	80	85	70	75		
/duus/	130	85	115	100	115	125	110	0	0.002**
/dus/	65	65	60	70	70	75	70		

(1) The two asterisks (**) indicate that the two sets of data for the tokens of utterances show a statistically very significant difference at the level $p < 0.05$. This applies for all the tables included in this study.

Table 4.3.2 Durations in msec and Ratios of Long Vowels to Short Vowels according to the Average Values when all the Consonant Environments are pooled

Vowels	Average	Ratio
/aa/ /a/	175 87.5	2
/ii/ /i/	112.5 60	1.87
/uu/ /u/	117.5 72.5	1.62

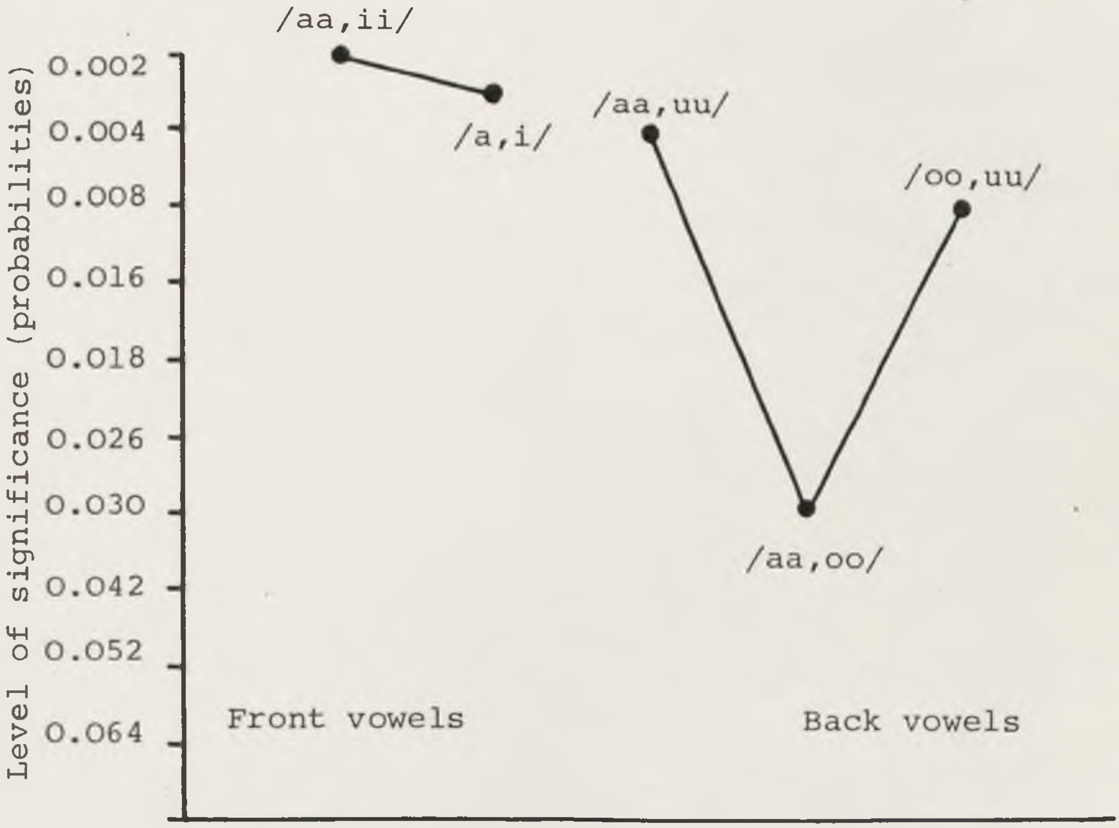


Fig. 4.8

Level of significance (p values) of paired sets of vocoids according to their intrinsic duration. This figure corresponds to table 4.3.1. Words chosen (front vowels); /daas/ versus /diis/, /das/ versus /dis/, (back vowels); /saaɣ/ versus /suuɣ/, /saaɣ/ versus /sooɣ/, and /sooɣ/ versus /suuɣ/respectively. The first symbol stands for the longer vocoid duration. (The smaller the probability, the more significant the difference.) (Mann Whitney U test).

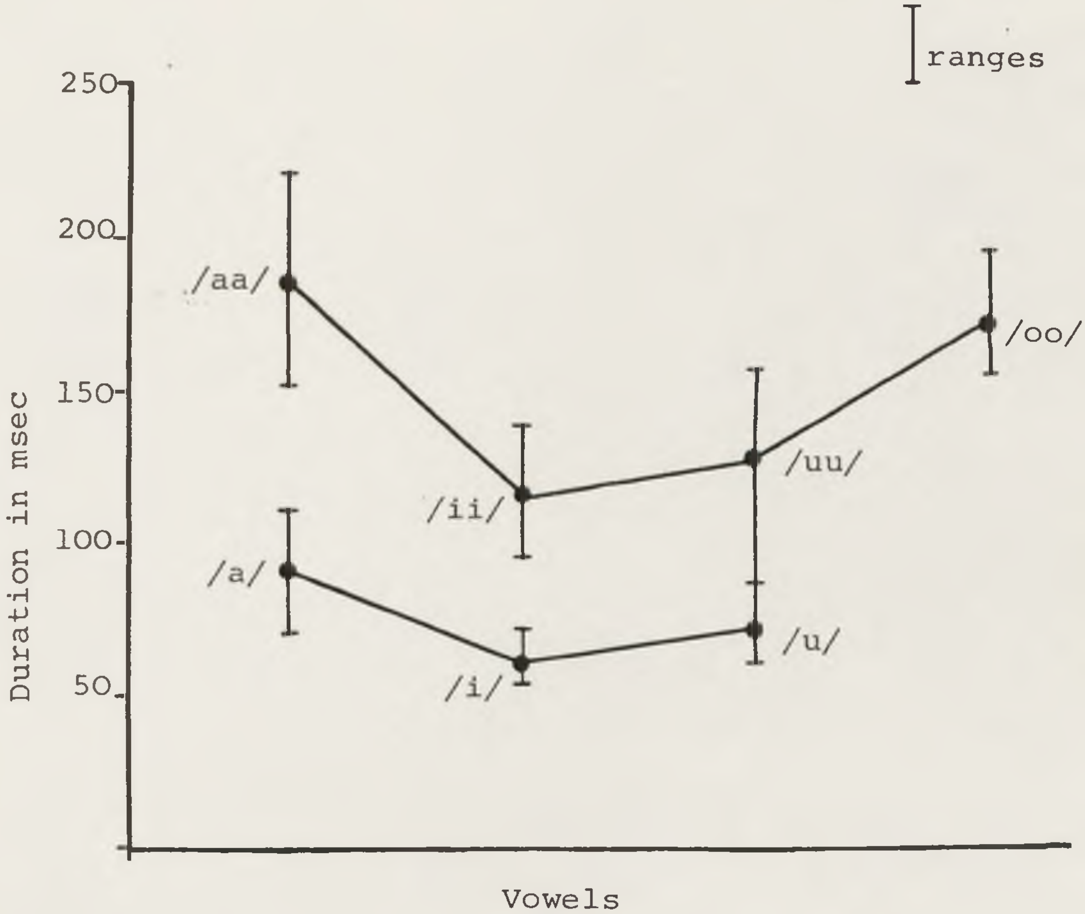


Fig. 4.9

Average values of vocoids when all the contoid environments are pooled. This figure corresponds to table 4.3.1.

and Six, are consistent with the hypothesis put forward by House (1961) and validated by the data reported by Lindblom (1968) and Condax & Krones (1976), as reviewed in section 2.2.1, in that lengthening found in long vowels appears to be deliberately made by the speaker for phonological purposes whereas lengthening found in open vowels is a function of the articulatory processes themselves.

4.3.2 Voicing and Manner of Articulation

Table 4.4.1 shows measurements in msec of vocoids according to the voicing and manner of articulation of the following contoids. It is subdivided into two categories; the first deals with the voicing of the following contoid which is subdivided into: (a) dealing with the following voiced versus voiceless fricatives, and (b) dealing with the following voiced versus voiceless plosives, for both long and short vowels; the second category deals with the following emphatic versus non-emphatic contoids which is also subdivided into: (a) dealing with the following voiceless emphatic versus non-emphatic fricatives and (b) dealing with the following voiceless emphatic versus non-emphatic plosives, also for both long and short vowels. The vowels chosen for these comparisons are /aa/ and /a/. Apart from /daaɣ/ versus /daax/ all the monosyllabic words compared begin with /b/ forming similar and symmetrical phonetic contexts for all the categories and subdivisions concerned.

As attested by category 1 for (a) and (b) all vocoids followed by voiced contoids are invariably longer† than those followed by the corresponding voiceless contoids and this durational difference is statistically very significant. However, the level of significance varies according to the manner of articulation of the contoids concerned as illustrated by figure 4.10 which correspond to table 4.4.1. p values for voiced versus voiceless fricatives in 1(a) for both long and short vowels which are at levels p = 0.002 and p = 0.004 are higher than those for voiced versus voiceless plosives in 1(b) which are at level less than p = 0.004 for /baad/ versus /baat/ (long vowels) and level p = 0.042 for /bad/ versus /bat/ (short vowels).†

The second category of the same table for both (a) and (b) shows that all vocoids followed by emphatic contoids are longer than those followed by non-emphatic contoids. However, the level of significance also varies according to the manner of articulation of the contoids concerned. As attested by the data shown here, p values for the durational difference of vocoids preceding emphatic versus non-emphatic plosives are higher than those preceding emphatic versus non-emphatic fricatives for both long and short vowels. See for example /baaṯ/

---

† Please refer to the statistical note on page 200a.

Table 4.4.1 Duration Measurements in msec of Vocoids according to the Voicing and Manner of Articulation of the Following Contoid

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Following voiced versus voiceless contoids									
(a) Voiced versus voiceless fricatives									
/daaɣ/	225	200	220	235	210	185	215	0	0.002**
/daax/	155	155	155	180	155	180	165		
/baaz/	185	195	210	220	200	185	200	0	0.004**
/baas/	170	-	155	165	140	155	155		
/baz/	95	110	115	110	105	115	110	0	0.002**
/bas/	85	75	75	80	80	80	80		
(b) Voiced versus voiceless plosives									
/baad/	170	170	165	180	160	155	165	0.5	less than 0.004**
/baat/	150	150	150	155	150	150	150		
/bad/	80	75	85	85	85	85	85	5†	0.042**
/bat/	75	80	80	80	70	70	75		

Table 4.4.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
2. Following emphatic versus non-emphatic contoids									
(a) Voiceless fricatives									
/baas/	195	170	170	180	170	165	175	3	** 0.03
/baas/	170	-	155	165	140	155	155		
/bas/	95	85	80	90	80	95	85	† 5.5	* (1) less than 0.064
/bas/	85	75	75	80	80	80	80		
(b) Voiceless plosives									
/baat/	165	160	155	165	160	155	160	† 1	** 0.004
/baat/	150	150	150	155	150	150	150		
bat	80	80	85	85	85	80	85	† 4.5	** less than 0.042
bat	75	80	80	80	70	70	75		

(1) (*) indicates that the two sets of data for the tokens of this pair of utterances show a statistically significant difference at the level $p > 0.05$ and $p < 0.07$. This applies for all the tables included in this study.

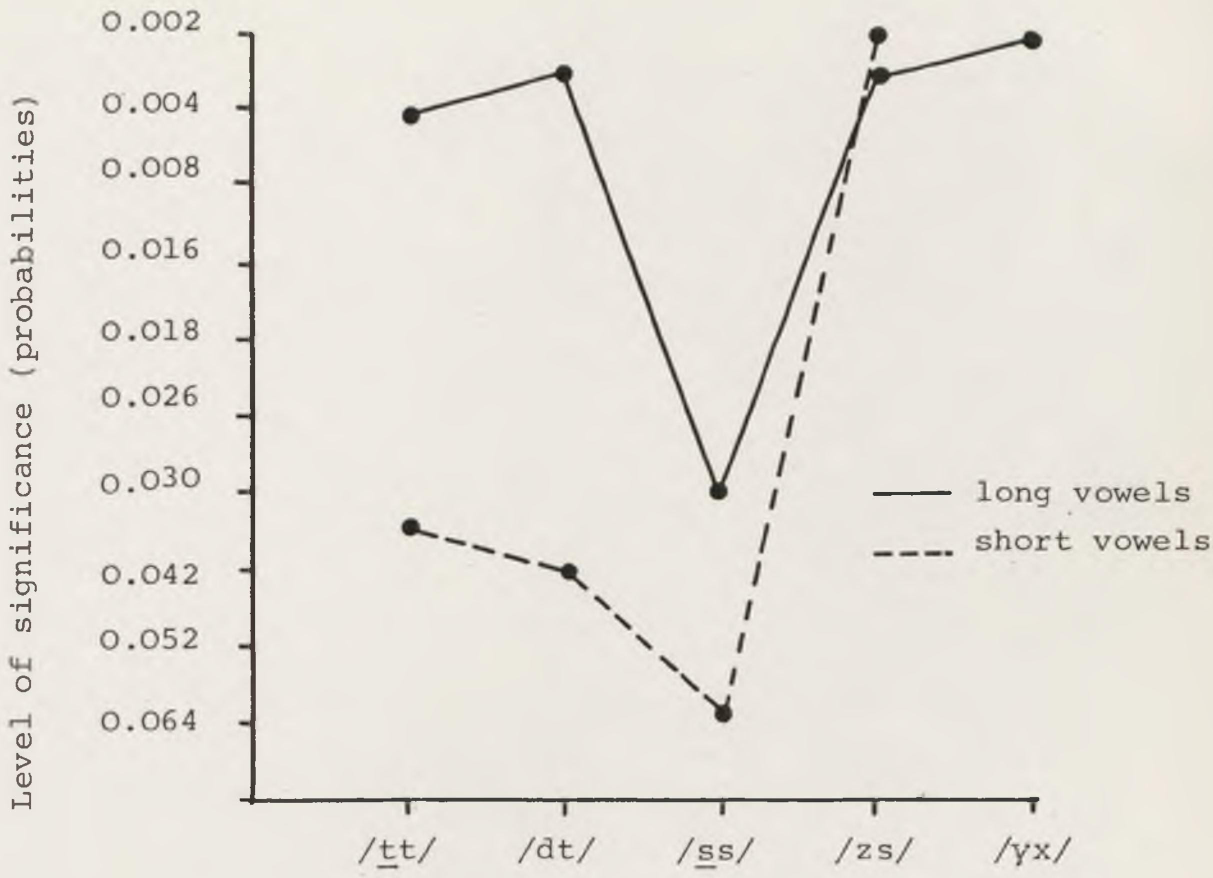


Fig. 4.10

Level of significance (p values) for pairs of vocoid duration according to the voicing and manner of articulation of the following contoid. This figure corresponds to table 4.4.1. (The smaller the probability, the more significant the difference.) (Mann-Whitney U test.)

versus /baat/ and /bat̲/ versus /bat/ where the differences are statistically very significant at levels p = 0.004 and less than p = 0.042 respectively, whereas those for /baas̲/ versus /baas/ and bas̲/ versus /bas/ are at levels p = 0.03 (very significant) and less than p = 0.064 (significant).†

It is also interesting to observe the general tendency that p values are less in sequences with short vowels than in sequences with their counterpart long vowels for both (a) and (b).

This experiment was mainly conducted to investigate the durational differences of vocoids in as much as the following voiced versus voiceless contoids and emphatic versus non-emphatic contoids are concerned. Nevertheless, it is interesting to observe how vocoid duration varies according to the manner of articulation of the following contoids as attested by the average values of vocoid duration in each set. Figure 4.11 as well as Table 4.4.1 shows that, according to their average values, vocoids before z > s̲ > d > t̲ > s > t for long vowels and z > d = s̲ = t̲ > s > t[(1)] for short vowels. Figure 4.11 also shows that the patterns are similar for long and short vowels suggesting that the variations in question are not haphazard but instead indicate law

---

(1) Consonant symbols refer to the preceding vocoids. > stands for "longer than" and = stands for "equal to".

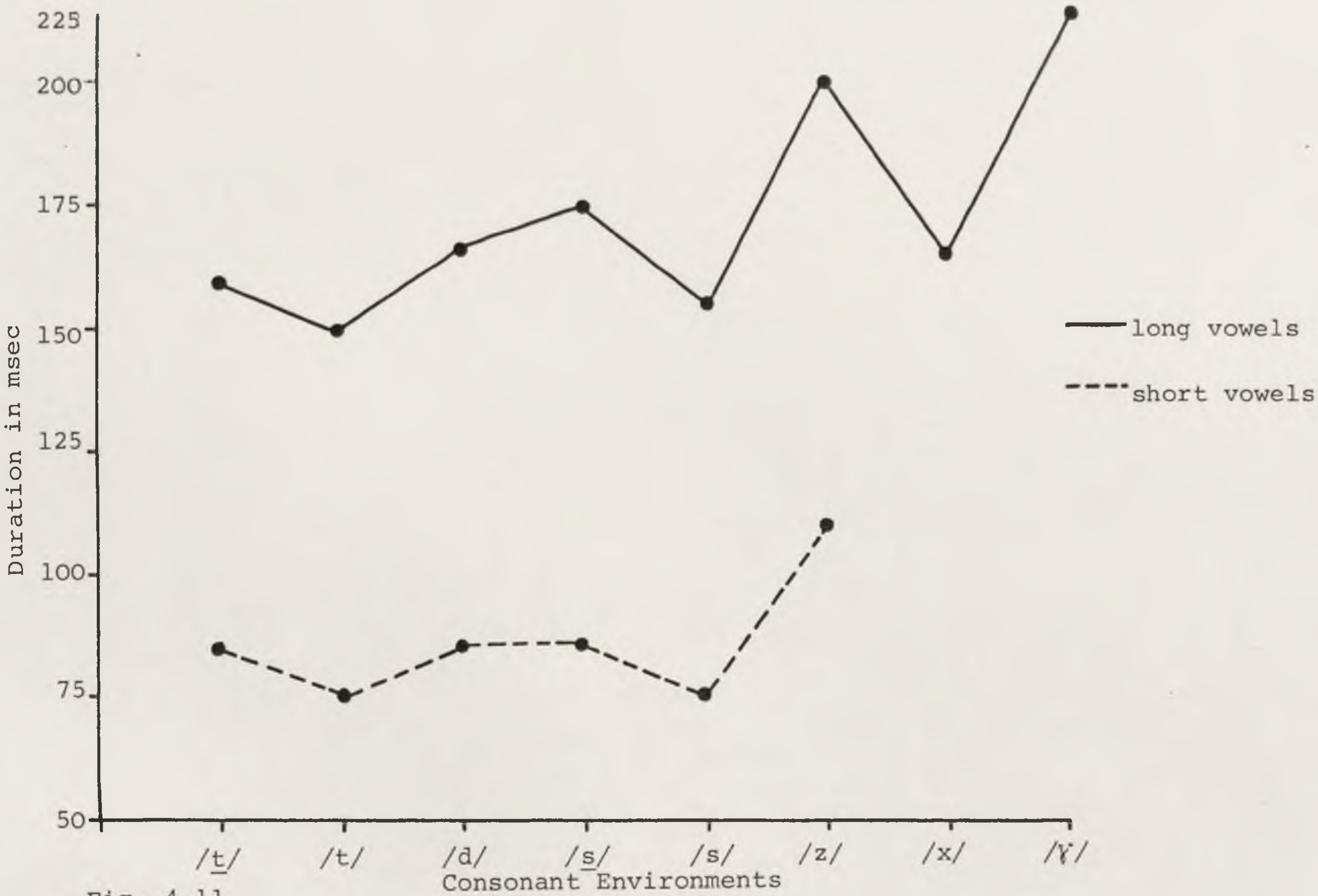


Fig. 4.11

Average values of vocoid duration according to the voicing and manner of articulation of the following contoid. Vowels chosen are /aa/ and /a/. This figure corresponds to table 4.4.1.

governed regularities very likely conditioned by speech production mechanism.

Table 4.4.2 shows measurements of vocoid duration in msec according to the influence of the preceding contoid in as much as voicing and manner of articulation are concerned. It shows that the difference is statistically non-significant in all the cases. These results suggest that the influence of the preceding contoid on the following vocoid in as much as voicing and manner of articulation are concerned seems to be negligible and signifies no important or interesting value.

Our findings concerning the influence of voicing of the following contoids on the duration of the preceding vocoids are in remarkable agreement with the findings of the previous studies and in particular those of House & Fairbanks (1953), Peterson & Lehiste (1960) and Chen (1970) (see section 2.3.1), but with the ratio being 0.74 for fricatives and 0.90 for plosives when long and short vowels are pooled. As for the manner of articulation of the following contoid and in as much as the comparison that our data could permit, it seems that our findings are also in agreement with those obtained by House & Fairbanks (1953) where the general tendency is that voiced fricatives > voiced plosives > voiceless fricatives > voiceless plosives. They are also in agreement with the data of Peterson & Lehiste (1960)

Table 4.4.2 Duration Measurements in msec of Vocoids according to the Voicing and Manner of Articulation of the Preceding Contoid

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Voiced versus voiceless fricatives									
/zaad/	210	185	200	195	200	200	200	11.5	(-)[1] less than 0.394
/saad/	210	180	195	195	195	195	195		
2. Voiced versus voiceless plosives									
/dal/	100	90	90	80	75	90	90	7.5	(-) less than 0.132
/tal/	70	80	90	70	85	75	80		
3. Emphatic versus non-emphatic contoids									
(a) Fricatives									
/saad/	185	190	185	200	230	195	195	17	(-) 0.938
/saad/	210	180	195	195	195	195	195		
/sad/	80	75	80	85	85	85	80	11.5	(-) less than 0.394
/sad/	75	75	80	80	85	80	80		
(b) Plosives									
/taab/	180	190	200	175	205	190	190	10.5	less than 0.31
/taab/	180	185	180	175	185	190	185		

(1) (-) indicates that the two sets of data for the tokens of this pair of utterances show a statistically non-significant difference at the level $p > 0.07$. This applies for all the tables included in this study.

where vowels before voiced fricatives have considerably longer duration than those preceding voiced plosives. This study has also confirmed the findings of Peterson & Lehiste (1960) concerning the negligible influence of the voicing and manner of articulation of the preceding contoid on vocoid duration.

Table 4.4.3 shows the influence of emphatic contoids on vocoid duration. It presents an interesting problem which has not been studied in detail before. The words were selected to see how vocoid duration behaves when the vocoid is surrounded by sequences of emphatic versus non-emphatic contoids. This table includes duration measurements in msec of vocoids as preceded and followed by four sequences of emphatic versus non-emphatic contoids: (1) voiceless emphatic versus non-emphatic fricatives; (2) voiceless emphatic versus non-emphatic plosives; (3) voiced emphatic versus non-emphatic plosives and, (4) emphatic versus non-emphatic contoids chosen at random. In all these cases vocoids are considerably longer when they are surrounded by emphatics than when they are surrounded by non-emphatics and this durational difference is statistically very significant in all cases, as in /s̲aas̲/ versus /saas/ where $p = 0.018$, /t̲uut̲/ versus /tuut/ where $p = 0.004$, /b̲aab̲a/ versus /baaba/ where $p = 0.016$ and /r̲af̲/ versus /raf/ where $p = 0.002$.

Table 4.4.3 Duration Measurements in msec of Vocoids when Preceded and Followed by Emphatic versus Non-emphatic Contoids

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Voiceless fricatives									
/saas/	195	180	195	200	220	205	195	1.5	** less than 0.018
/saas/	160	-	165	165	180	165	165		
2. Voiceless plosives									
/tuut/	180	170	170	165	170	165	170	1	** 0.004
/tuut/	150	110	115	150	165	150	140		
3. Voiced plosives									
/baaba/	180	210	200	210	195	185	195	2.5	** less than 0.016
/baaba/	180	165	170	180	185	155	175		
4. Emphatics versus non-emphatics chosen at random									
/raf/	130	115	110	125	115	115	120	0	** 0.002
/raf/	100	95	105	100	100	100	100		

The findings of this table seems to confirm the data of table 4.4.1 in that emphatic contoids have considerable influence on vocoid duration. This problem will be investigated further in Chapter Five and discussed in more detail in Chapter Six.

4.3.3 Place of Articulation

Table 4.5.1 shows how vocoid duration varies according to the place of articulation of the following contoid. It is subdivided into three categories. Contoids were chosen to represent front-to-back pattern for each category in the following order:

(a) Voiceless Fricatives

labio-dental /f/ ⟶ denti-alveolar /s/ ⟶ palato-alveolar /ʃ/ ⟶ uvular /x/ ⟶ pharyngeal /ħ/.

(b) Voiced Fricatives

denti-alveolar /z/ ⟶ uvular /ɣ/ ⟶ pharyngeal /ʕ/.

(c) Voiceless Plosives

denti-alveolar /t/ ⟶ uvular /q/ ⟶ glottal /ʔ/.

As attested by the data shown in this table all vocoids preceding back contoids are considerably shorter than all those preceding the rest of the contoids compared in each category and the durational difference is always statistically very significant. As has always been the case, the level of significance also varies here. In category (a) the highest level of significance is between /faas/ versus /faaħ/ and /faaʃ/ versus /faaħ/ where the difference is at the level p = 0.002 whereas the differences between /faax/ versus /faaħ/ and /faaf/ versus /faaħ/ are at the levels p = 0.004 and p = 0.026 respectively. In category (b) the highest level of significance is between /baaz/ versus /baaʕ/ where the difference is at the level p = 0.002 whereas it is at p = 0.008 between /baaɣ/ versus /baaʕ/. The same is true for category (c) where the differences are at the levels p = 0.008 and p = 0.042 for /faat/ versus /faaʔ/ and /faaq/ versus /faaʔ/ respectively.

It can be very clearly concluded from the above data that the highest level of significance is always between denti-alveolar and/or palato alveolar and corresponding pharyngeal and/or glottal contoids for all the three categories concerned.

Our findings concerning the durational variations of vocoids according to front-to-back positions of the following contoids contradict the hypothesis put forward by Delattre (1962) that vocoid lengthening is proportional to front-to-back pattern of the following contoid position (see section 2.3.2). Our data shown in Table 4.5.1 and illustrated in Figures 4.12 and 4.13 suggest that for I.S.A. vocoids are longer when they are

Table 4.5.1 Duration Measurements in msec of Vocoids According to the Place of Articulation of the Following Contoid (with Open Vowels)

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
(a) Voiceless fricatives									
1. labio-dental versus denti-alveolar									
/faaf/	165	160	150	180	130	160	160	8.5	(-) less than 0.18
/faas/	170	170	150	180	180	170	170		
2. labio dental versus palato alveolar									
/faaf/	165	160	150	180	130	160	160	15	(-) 0.7
/faaʃ/	185	165	150	160	165	150	165		
3. labio dental versus uvular									
/faaf/	165	160	150	180	130	160	160	13	0.484
/faax/	165	140	135	160	155	150	150		
4. labio dental versus pharyngeal									
/faaf/	165	160	150	180	130	160	160	3.5	** less than 0.026
/faaħ/	135	125	130	135	130	130	130		

Table 4.5.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
5. denti alveolar versus palato alveolar									
/faas/	170	170	150	180	180	170	170	10	(-) 0.240
/faaʃ/	185	165	150	160	165	150	165		
6. denti alveolar versus uvular									
/faas/	170	170	150	180	180	170	170	3.5	** less than 0.026
/faax/	165	140	135	160	155	150	150		
7. denti alveolar versus pharyngeal									
/faas/	170	170	150	180	180	170	170	0	** 0.002
/faaħ/	135	125	130	135	130	130	130		
8. palato alveolar versus uvular									
/faaʃ/	185	165	150	160	165	150	165	9.5	(-) less than 0.240
/faax/	165	140	135	160	155	150	150		
9. palato alveolar versus pharyngeal									
/faaʃ/	185	165	150	160	165	150	165	0	** 0.002
/faaħ/	135	125	130	135	130	130	130		
10. uvular versus pharyngeal									
/faax/	165	140	135	160	155	150	150	1	** 0.004
/faaħ/	135	125	130	135	130	130	130		

Table 4.5.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
(b) Voiced fricatives									
1. denti alveolar versus uvular									
/baaz/	185	195	210	220	200	185	200	3	** .016
/baaɣ/	180	160	170	185	165	190	175		
2. denti-alveolar versus pharyngeal									
/baaz/	185	195	210	220	200	185	200	0	** 0.002
/baaʕ/	145	130	150	155	150	165	150		
3. uvular versus pharyngeal									
/baaɣ/	180	160	170	185	165	190	175	1.5	** less than 0.008
/baaʕ/	145	130	150	155	150	165	150		
(c) Voiceless Plosives									
1. denti alveolar versus uvular									
/faat/	145	155	150	150	155	135	150	15	(-) 0.7
/faaq/	165	180	140	155	150	130	155		
2. denti alveolar versus glottal									
/faat/	145	155	150	150	155	135	150	2	** 0.008
/faaʔ/	145	130	135	130	130	130	135		

Table 4.5.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
3. uvular versus glottal									
/faaq/	165	180	140	155	150	130	155	5	0.042**
/faaʔ/	145	130	135	130	130	130	135		

followed by denti alveolar contoids and shorten as the constriction of the following contoid is executed further back into the rear section of the vocal tract and not as Delattre claims.

As regards the other members of the groups compared in each category, in so far as level of significance is concerned, our data do not yield a consistent pattern. The only significant differences are between /baaz/ versus /baaɣ/ at the level p = 0.016 (statistically very significant) and between /faas/ versus /faax/ at the level p = 0.026 (statistically very significant).

Nevertheless, in so far as the average values of each set are concerned, in category (a) (voiceless fricatives) the general tendency is that vocoids are longer before denti-alveolar > palato alveolars > labio-dental > uvulars > pharyngeals. In category (b) (voiced fricatives) the tendency is that vocoids are longer before denti-alveolars > uvulars > pharyngeals. In category (c) (voiceless plosives) vocoids before uvulars > denti-alveolars > glottals. These findings have been illustrated in figure 4.12. In this respect our data generally seem to be in agreement with those obtained by House & Fairbanks (op. cit.) if we exclude pharyngeals and glottals from the comparison. They found, as reviewed in section 2.3.2, that vocoids before post-dentals > bilabials > Velars.

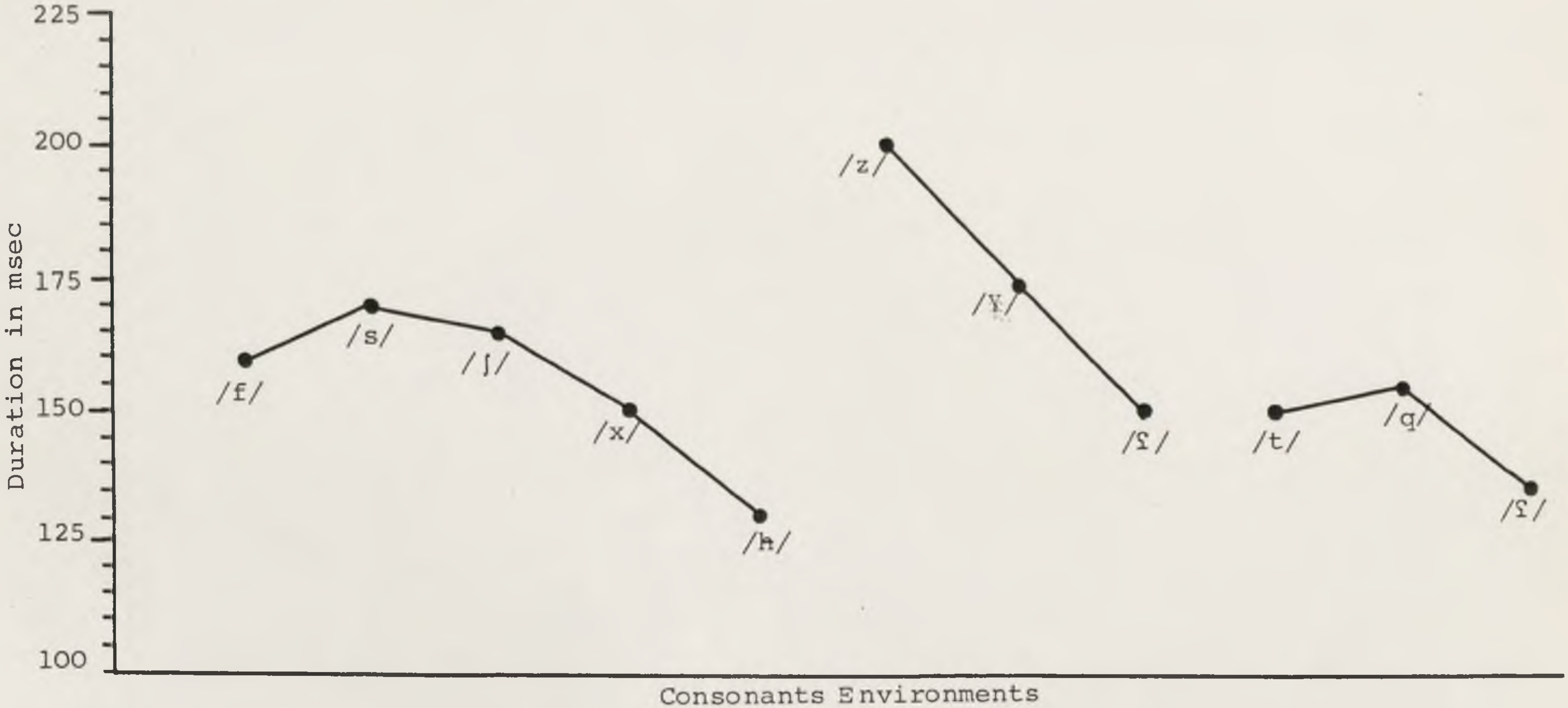


Fig. 4.12

Average values of vocoid duration according to the place of articulation of the following contoid. Vowel chosen is /aa/. This figure corresponds to table 4.5.1.

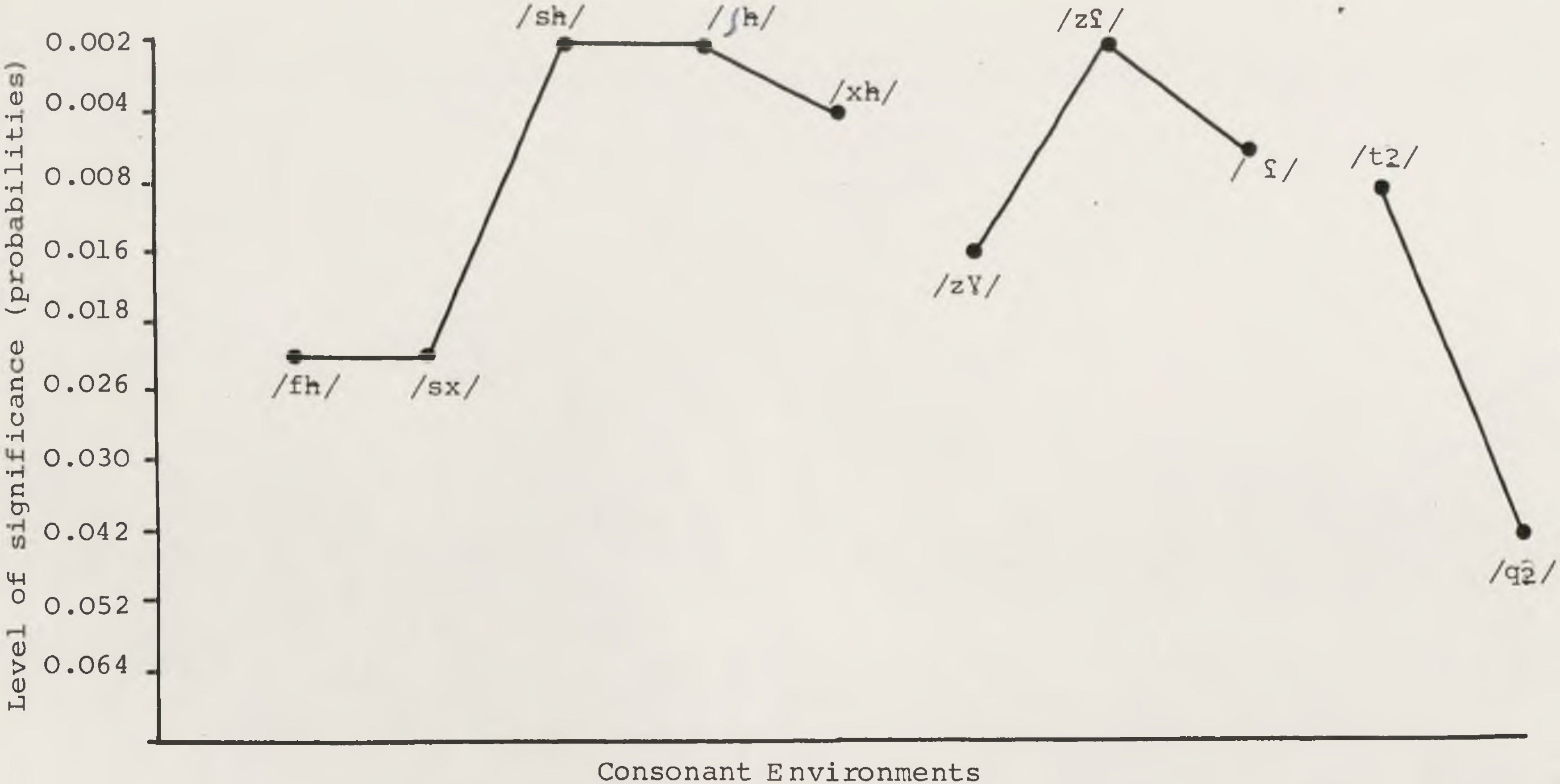


Fig. 4.13

Level of Significance (p values) for pairs of vocoid durations according to the place of articulation of the following contoid. This figure corresponds to table 4.5.1. (The smaller the probability, the more significant the difference. (Mann-Whitney U test). The first symbol stands for the longer preceding vocoid.

Table 4.5.2 deals with our attempt to test whether some front versus back contoids have the same influence on the preceding vocoid when the vowel is close and not open as in Table 4.5.1. We have also been interested to find out whether there is any durational difference between vocoids according to the place of articulation of the vowel itself and not only of the following contoid as in Table 4.5.1. This table is subdivided into two categories. The first category includes measurements of vocoid duration in msec before voiceless denti-alveolar /ʃ/ versus pharyngeal /ħ/ fricatives. The second category includes measurements of vocoid duration in msec in minimal pairs containing close front versus close back vowels. For the first category the table shows that vocoids are longer before a voiceless palato-alveolar fricative than before a voiceless pharyngeal fricative according to the average values for each set of tokens. However, in so far as level of significance is concerned the durational difference is statistically significant† only in /riiʃ/ versus /riiħ/ at level $p = 0.064$ where the vowel is close front whereas the durational difference is statistically non-significant in /ruuʃ/ versus /ruuħ/ at level $p > 0.07$ where the vowel is close back.

For the second category the table shows that according to the average values of vocoid duration all back close vowels (long and short) are longer than their corresponding front close vowels (long and short). However, in so far

Table 4.5.2 Measurements of Duration in msec of Vocoids according to: (1) Place of Articulation of the Following Consonant (Front versus Pharyngeal) with Close Vowels; (2) Place of Articulation of the Vowel Itself (Close Front versus Close Back)

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
1. Following palato-alveolar versus pharyngeal fricatives									
/riiʃ/	195	175	180	165	190	180	180	6 †	* 0.064
/riiħ/	165	175	165	160	165	180	170		
/ruuʃ/	200	180	180	170	195	-	185	6.5	(-) less than 0.094
/ruuħ/	165	180	190	170	165	175	175		
2. Close front versus close back vowels									
/ruuʃ/	200	180	180	170	195	-	185	18.5	(-) -
/riiʃ/	195	175	180	165	190	180	170		
/ruuħ/	165	180	190	170	165	175	175	11	(-) 0.31
/riiħ/	165	175	165	160	165	180	170		
/ʕud/	65	70	85	80	85	70	75	1	** 0.004
/ʕid/	65	60	60	50	65	60	60		

Table 4.5.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
/dus/	65	65	60	70	70	75	70	6 †	0.064 *
/dis/	70	55	65	55	55	55	60		
/ʕuud/	110	135	115	150	115	135	125	13	(−) 0.588
/ʕiid/	115	100	115	115	135	125	120		
/duus/	130	85	115	100	115	125	110	11.5	(−) less than 0.394
/diis/	100	95	95	110	115	115	105		

as level of significance is concerned the durational differences are statistically very significant† only in two cases; in /Ʃud/ versus /Ʃid/ where the difference is at p = 0.004 and in /dus/ versus /dis/ where the difference is at p = 0.064 whereas in all the other cases the durational difference is statistically non-significant.

As regards the first category the data shown in this table support the evidence† attested by the data in Table 4.5.1 that vocoids are shorter before pharyngeal and/or glottal contoids than when they are before contoids the constrictions of which are executed (roughly speaking) in the front or the middle of the vocal tract i.e. bilabial, denti-alveolar palato-alveolar and uvular contoids and validates the assumption that the tendency is there no matter whether the vowel is open or close. Though the difference in /ruuʃ/ versus /ruuħ/ failed to show any statistically significant value, in so far as the average values are concerned it showed a direction of difference consistent with the other minimal pairs compared for the same purpose. Other implications are also shown by both tables which will be discussed in Chapters Five and Six.

As regards the second category, though the table does not show a consistent pattern in as much as level of significance is concerned, it shows that the data according to the average values are similar to those obtained by Fischer-Jørgensen (1964) who found, as reviewed in Section 2.3.2, that '[u] is on the whole longer than [i]' (op. cit. p.191).

4.3.4 Stress and Vowel Duration

Duration measurements in (msec), Fo measurements in (Hz) and Intensity measurements in (dB) of vocoids in stressed versus unstressed syllables are arranged in tables (see Sections 4.2.6.2 and 4.2.6.3 for details of the criteria of measuring Fo and intensity). Words were selected to investigate the influence of stress on vowel duration and the roles of vowel duration, Fo and intensity as acoustic correlates of stress. Two minimal or nearly minimal pairs were selected for each table in so far as the phonological system of I.S.A. permits and accordingly they were arranged in the following order:

(i) Table 4.6.1 includes sequences of stressed versus unstressed syllables in two bisyllabic words of identical syllable structure where a shift of stress from the first to the second syllable corresponds to difference in meaning as in /'ʃirbuu/ versus /ʃir'buu/ and /'ʃirbii/ versus /ʃir'bii/.

(ii) Table 4.6.2 includes sequences of stressed versus unstressed syllables in two similar bisyllabic words (not identical) where a shift of stress from the first to the second is associated with a change in syllabic length (from short to long syllable) i.e. it is associated with a change in the phonological structure of the word and consequently a difference in meaning as in /'kitab/ versus /ki'taab/ and /'sitar/ versus /si'taar/.

(iii) Table 4.6.3 includes syllables having primary stress versus secondary stress in bisyllabic versus three syllable and three syllable versus four syllable words where the same long syllable undergoes a shift of stress from a secondary to a primary stress and an addition of another long stressed syllable as in /ʕad'daad/ versus /ʕadˌdaa'daat/ and /ʔistiʕ'daad/ versus /ʔistiʕˌdaa'daat/.

4.3.4.1 <u>The Influence of Stress on Vowel Duration</u>

Duration measurements of the target vocoids in msec in all the three tables show that vocoids in stressed syllables are considerably longer than those in unstressed syllables. The durational differences in all the phonetic contexts selected are statistically very significant. Table 4.6.2 for 1(a) and 2(a) show a relatively lower level of significance, where the differences are at $p = 0.008$ and $p = 0.018$ respectively, than both 4.6.1 for 1(a) and 2(a) and Table 4.6.3 for 1(a) and 2(a) where the difference is always $p = 0.002$. In so far as Table 4.6.1 is concerned where the comparison is feasible because of similar phonological structure our data seem to be in remarkable agreement with the data reported by Fry (1955), Parmental & Trevino (1935), Tiffany (1959) and Delattre (1966) as reviewed in section 2.4.2, indicate that the influence of stress on vocoid duration is cross-linguistically valid.

4.3.4.2 Vowel Duration as an Acoustic Correlate of Stress

Duration measurements in msec, Fo measurements in Hz and intensity measurements in dB included in Tables 4.6.1, 4.6.2 and 4.6.3 suggest that vocoid duration in comparison with theother acoustic correlates i.e. Fo and intensity plays a more important role as an acoustic correlate of stress in I.S.A. Table 4.6.1 for 1 and 2 shows that the differences for vocoid duration and Fo are all at level p = 0.002 whereas the differences for intensity† are at levels p = 0.042 and p = less than 0.064 respectively i.e. the roles of vocoid duration and Fo seem likely to outweigh the role of intensity. Table 4.6.2 for 1 and 2, however, suggests that the role of vocoid duration where the differences are at p = 0.008 and p = 0.018 is outweighed by the role of Fo where the differences are both at p = 0.002. Still, the level is statistically very significant and more significant than for intensity the differences† for which are at less than p = 0.064 and p = 0.240 for 1 and 2 respectively. Nevertheless, Table 4.6.3 for 1 and 2 suggests that vocoid duration outweighs the

Table 4.6.1 Vocoid Duration Measurements in msec, Fo Measurements in Hz and Intensity Measurements in dB of Sequences of Stressed versus Unstressed Syllables in Two Bisyllabic Words of Identical Syllable Structure where a Shift of Stress from the First to the Second Syllable Corresponds to a Difference in Meaning

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
1. /ʃir'buu/ versus /'ʃirbuu/									
(a) Vocoid duration									
/ʃir'buu/	155	160	180	155	200	195	175	0	0.002**
/'ʃirbuu/	95	85	90	100	95	100	95		
(b) Fo									
/ʃir'buu/	130	150	120	155	120	125	135	0	0.002**
/'ʃirbuu/	100	110	100	100	90	90	100		
(c) Intensity									
/ʃir'buu/	45	45	45	40	38	39	42	5 †	0.042**
/'ʃirbuu/	38	40	39	38	30	38	35		

Table 4.6.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
2. /ʃir'bii/ versus /'ʃirbii/									
(a) Vocoid duration									
/ʃir'bii/	115	115	150	140	175	160	145	0	0.002**
/'ʃirbii/	95	70	55	60	80	95	75		
(b) Fo									
/ʃir'bii/	125	125	125	125	120	130	125	0	0.002**
/'ʃirbii/	100	100	95	100	105	100	100		
(c) Intensity									
/ʃir'bii/	46	45	47	47	36	41	44	5.5	† ** less than 0.064
/'ʃirbii/	40	42	41	40	34	30	38		

Table 4.6.2 Vocoid Duration Measurements in msec, Fo Measurements in Hz and Intensity Measurements in dB for the Underlined Vowels in Sequences of Stressed versus Unstressed Syllables in in two Bisyllabic Words which differ in Stress Placement

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
1. /'kitab/ versus /ki'taab/									
(a) Vocoid duration									
/'k_i_tab/	40	35	45	40	70	60	50	2	0.008**
/k_i_'taab/	25	25	25	40	30	25	30		
(b) Fo									
/'k_i_tab/	160	155	155	160	155	155	157	0	0.002**
/k_i_'taab/	125	120	125	110	110	120	118		
(c) Intensity									
/'k_i_tab/	47	44	47	48	42	39	44.5	5.5 †	** less than 0.064
/k_i_'taab/	41	40	42	43	26	23	36		
2. /'sitar/ versus /si'taar/									
(a) Vocoid duration									
/'s_i_tar/	45	40	40	45	45	45	45	2	0.018**
/s_i_'taar/	25	-	35	30	40	40	35		

Table 4.6.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
(b) Fo									
/'si̲tar/	150	180	180	170	130	140	158	2.5	** less than 0.016
/si̲'taar/	120	120	150	120	100	110	120		
(c) Intensity									
/'si̲tar/	47	47	48	42	30	34	41.5	10	(-) 0.240
/si̲'taar/	40	34	45	42	32	26	36.5		

Table 4.6.3 <u>Vocoid Duration Measurements in msec, Fo Measurements in Hz and Intensity Measurements in dB of Sequences of Primarily Stressed versus Secondarily Stressed Syllables in Words having Different Numbers of Syllables</u>

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
1. Bisyllabic versus three syllable word. /ʕad'daad/ versus /ʕad,daa'daat/									
(a) Vocoid duration									
/ʕad'daad/	180	170	180	195	195	195	185	0	0.002**
/ʕad,daa'daat/	140	135	125	140	150	140	140		
(b) Fo									
/ʕad'daad/	105	105	115	110	120	150	117.5	4.5 †	less than 0.042**
/ʕad,daa'daat/	105	105	100	110	90	100	102		
(c) Intensity									
/ʕad'daad/	48	54	50	53	47	47	50	6 †	0.064*
/ʕad,daa'daat/	47	47	49	47	42	45	46		

Table 4.6.3 continued

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
2. Three syllable word versus four syllable word /ʔistiʕ'daad/ versus /ʔistiʕ'daadaadaat/									
(a) Vocoid duration									
/ʔistiʕ'-daad/	200	200	220	200	220	220	210	0	0.002**
/ʔistiʕ,-daa'daat/	140	135	150	140	150	130	140		
(b) Fo									
/ʔistiʕ'-daad/	110	115	130	120	110	115	117	3	0.016**
/ʔistiʕ,-daa'daat/	110	110	110	85	100	105	103		
(c) Intensity									
/ʔistiʕ-daad/	49	49	50	50	47	48	49	2	0.008**
/ʔistiʕ,-daa'daat/	47	46	46	48	44	45	46		

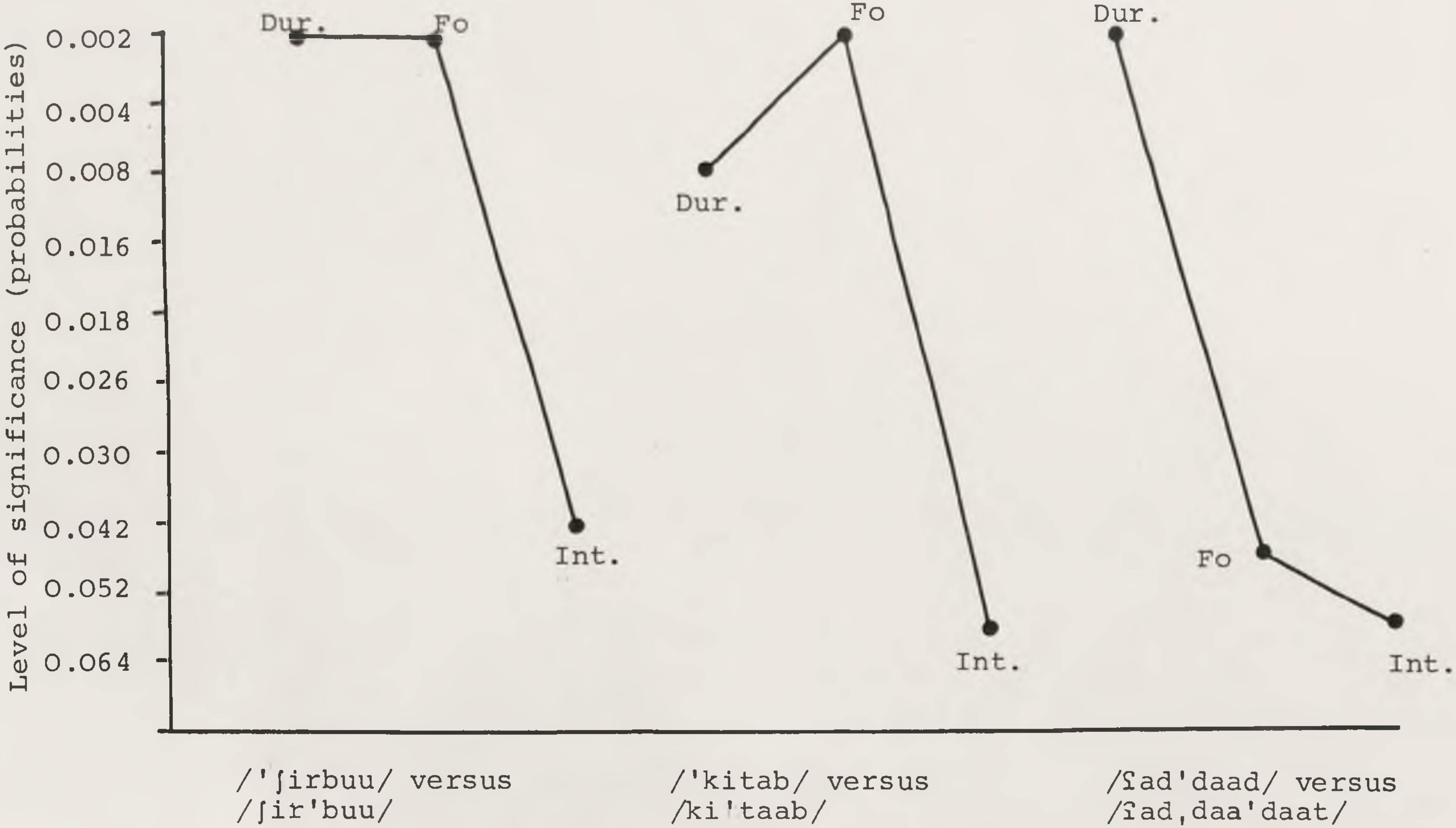


Fig. 4.14. Level of significance for measurements of duration in msec, Fo in Hz and intensity in dB of stressed versus unstressed syllables. The words chosen represent tables 4.6.1, 4.6.2 and 4.6.3 respectively. (The smaller the probability, the more significant the difference). (Mann-Whitney U test).

role of intensity and even Fo; differences for vocoid duration are both at p = 0.002 where the level of significance is higher than those for Fo at p = 0.042 and p = 0.016 and intensity at p = 0.64 and p = 0.008 respectively.

These findings as illustrated by Figure 4.14 strongly suggest that both vowel duration and Fo are important acoustic correlates of stress in I.S.A. A perceptual test, would be needed to indicate how much each of these acoustic correlates contributes to the perception of stress. Nevertheless, in so far as the acoustic data are concerned our findings seem to be in agreement with the data reported by Fry (1955) and (1958) and also with Lehiste's (1970) statement about the ambiguous role of intensity but disagree with the findings of Lieberman (1960) about the role of Intensity, as reviewed in Section 2.4.1.

4.3.5 The Influence of Intervocalic Geminates on Vowel Duration

Table 5.7 deals with the influence of intervocalic geminates on the duration of the preceding vocoids. The table is subdivided into two sections. The first section deals with the influence of intervocalic voiced and voiceless plosives and voiceless emphatic plosives on the preceding vocoid duration in two cases; (a) when the vocoid is in a stressed syllable as in /'fatih/ versus

/'fattiħ/, and (b) when it is in an unstressed syllable as in /fa'taat/ versus /fat'taat/. The second section deals with the influence of the intervocalic voiceless fricative on the preceding vocoid duration. The vowel chosen in both cases is /a/.

The data shown in this table indicate that vocoids are longer before non-geminate contoids than before geminate contoids for all the minimal pairs available and that the difference is statistically very significant in all the cases no matter whether the vocoid is followed by a voiced plosive, voiceless plosive, voiceless emphatic plosive or voiceless fricative in a stressed or unstressed syllable. Nevertheless, p values vary though they are all less than p = 0.05. As attested by the data shown for the first section in the same table p values for vocoids in unstressed syllables are much higher than those in stressed syllables as in /fa'taat/ versus /fat'taat/, and /sa'daad/ versus /sad'daad/, /ba'ṯaala/ versus /baṯṯaala/ where the differences are at less than p = 0.004, p = 0.004, and at less than p = 0.026 respectively, whereas they are at less than p = 0.026 and p = less than 0.03 for /'fatiħ/ versus /'fattiħ/ and /'ʕadad/ versus /'ʕaddad/ respectively. The table also shows that p values for the first category are all higher than the p value for the second category.

No matter whether a geminate is considered as a combination of two identical contoids or one long contoid, which is the case in I.S.A. as we shall see in Chapter Five

Table 4.7 Duration Measurements in msec of Vocoids preceding Intervocalic Geminates versus Non-geminates

Utterances	Tokens 1	2	3	4	5	6	Av.	U	p
1. Plosives									
/'fatiħ/	60	50	55	65	60	70	60	3.5	** less than 0.026
/'fattiħ/	55	50	45	55	45	45	50		
/'ʕadad/	65	95	80	95	65	95	80	3	** 0.03
/'ʕaddad/	50	55	65	-	50	75	60		
/fa'taat/	55	65	70	65	60	60	65	.5	** less than 0.004
/fat'taat/	45	45	55	45	50	45	50		
/sa'daad/	60	60	65	65	65	65	65	1	** 0.004
/sad'daad/	60	50	45	55	45	45	50		
/ba'taala/	70	80	80	85	75	65	75	3.5	** less than 0.026
/bat'taala/	70	60	65	55	70	60	65		
2. Fricatives									
/'baʃar/	80	80	80	80	85	80	80	5	** 0.042
/'baʃʃar/	65	60	60	60	80	80	65		

our data confirm Delattre's (1962) and (1971) statement that a vowel is shorter before a consonant cluster or a geminate consonant than before a single consonant. They are also consistent with Josselyn's (1901) findings on the shortening of the vowel preceding a geminate consonant. Our data also bear testimony to the fact stated by Thananjayarajansingham (1976) and Nootboom & Slis (1972) that long consonants are preceded by shorter vowels, as reviewed in Section 2.5.2.

4.4 Mean Differences of Vocoid Durations in I.S.A. as compared to Absolute (DLs) obtained by Henry (1948)

In our consideration of whether the minimal differences of Vocoid Duration obtained in this study are within the range that a human listener can detect i.e. above the just noticeable differences (JND's) or difference limens (DLs) we followed Lehiste (1970) and Chen (1970) in considering that Henry's(1948) and Stott's (1935) data are more appropriate for speech conditions (see Section 2.6). However, we believe that Henry's (op. cit.) data represent a reasonable compromise between Stott (op. cit.) and Ruhm et al (1966) whose data represent the limit of perceptibility under optimal conditions as reviewed in Section 2.6.

We selected some statistically very significant differences of vocoid duration obtained in this study and compared their mean differences with Weber ratios and absolute (DLs) for comparable reference durations established by Henry (op. cit.) considering mean differences of vocoid duration as equivalent to absolute (DLs) of Henry and average vocoid duration as comparable to reference duration (T) of Henry (1948).

Table 4.8 shows this comparison. Columns A, B and C represent Henry's data and columns D, E and F represent the data of this study as indicated by the footnotes below the same table.

The results of this comparison have been illustrated in Figure 4.15 where the absolute (DLs) or mean differences of vocoid duration are plotted against reference Duration or average vocoid duration showing a comparison between Henry's (op. cit.) data and the data of the present study on semilogarithmic graph paper.

As can be seen from comparing the crosses in this figure which represent columns D and E of Table 4.8 to the black dots representing columns C and A of the same table, despite the fact that the chosen vocoid differences are all statistically very significant, their mean durations considerably vary in relation to the (DLs) of Henry (op. cit.). They hover around the (DLs) concerned as in No.6 and No.10 or rose well above them as in No.7 and No.8 or fall below them as in No.11 and No.12.

Nevertheless, if we follow Lehiste (1970) in supposing that the range of DLs duration is usually from 10 to 40 msec in sequences ranging from 30 to 300 msec we see that in all our mean differences of vocoid durations none is below that range. Some of them are even higher as in /'ʃirbuu/ versus /ʃir'buu/, /daas/ versus /diis/ or /baaz/ versus /baas/ where the mean differences are 80, 50 and 45 for the average vocoid durations (comparable to reference durations) 135, 130 and 177.5 respectively.

In accordance with the above findings, we believe that differences of duration for all the sequences hovering around or above the DLs line are likely to be perceived by the listeners. Nevertheless, the degrees of perception vary considerably and for those sequences having higher mean differences of vocoid duration e.g. /'ʃirbuu/ versus /ʃir'buu/, the perception condition is certainly more acute than those having lower means e.g. /raf/, versus /raf/, even though the level of significance may be the same for both, which is in this case at level 0.002.

It remains dubious, however, whether all the statistically very significant mean differences which are higher than the range of DLs suggested by Lehiste (op. cit.) can have consequential phonological significance as we shall see in our discussion of these findings in Chapter Six.

Table 4.8 Comparison of Mean Differences of Vocoid Duration in Sequences Investigated in this Study with Weber Ratios and Absolute DLs for Comparable Reference Durations Established by Henry (1948)

HENRY (1948)			THE PRESENT STUDY			
A	B	C	D	E	F	
T	ΔT/T	Absolute DL in msec	Mean difference in msec	Average duration in msec	Sequences	Serial Numbers
47	0.203	9.54	20	40	/'kitab/ versus /ki'taab/	1
77	0.208	16.02	25	72.5	/das/ versus /dis/	2
			10	80	/bad/ versus /bat/	3
			10	80	/bat/ versus /bat/	4
			35	92.5	/baz/ versus /bas/	5
110	0.196	21.56	20	110	/raf/ versus /raf/	6
			50	130	/daas/ versus /diis/	7
			80	135	/ʃir'buu/ versus /'ʃirbuu/	8
			15	142.5	/faat/ versus /faaʔ/	9
			30	155	/tuut/ versus /tuut/	10
			10	155	/baat/ versus /baat/	11
			15	157.5	/baad/ versus /baat/	12
			45	162.5	/ʕad'daad/ versus /ʕaddaa'daat/	13
			55	167.5	/saaɣ/ versus /suuɣ/	14
175	0.188	32.90	50	175	/baaz/ versus /baaʕ/	15
			45	177.5	/baaz/ versus /baas/	16
			30	180	/saas/ versus /saas/	17

* Column A, B and C represent reference duration in msec, Weber ratios and absolute DLs in msec respectively as established by Henry (1948).

* Column D represents mean differences of vowel duration between sequences as indicated in Column F regarded as equivalent to absolute DLs established by Henry (1948).

Table 4.8 continued

* Column E represents Average vocoid duration of the sequences as indicated in Column F comparable to reference durations (T) of Henry (1948).

* Mean differences of vowel durations of Column D and Average vocoid duration of Column E are extrapolated from tables 4.3.1, 4.4.1, 4.4.2, 4.5.1, 4.6.1, 4.6.2 and 4.6.3

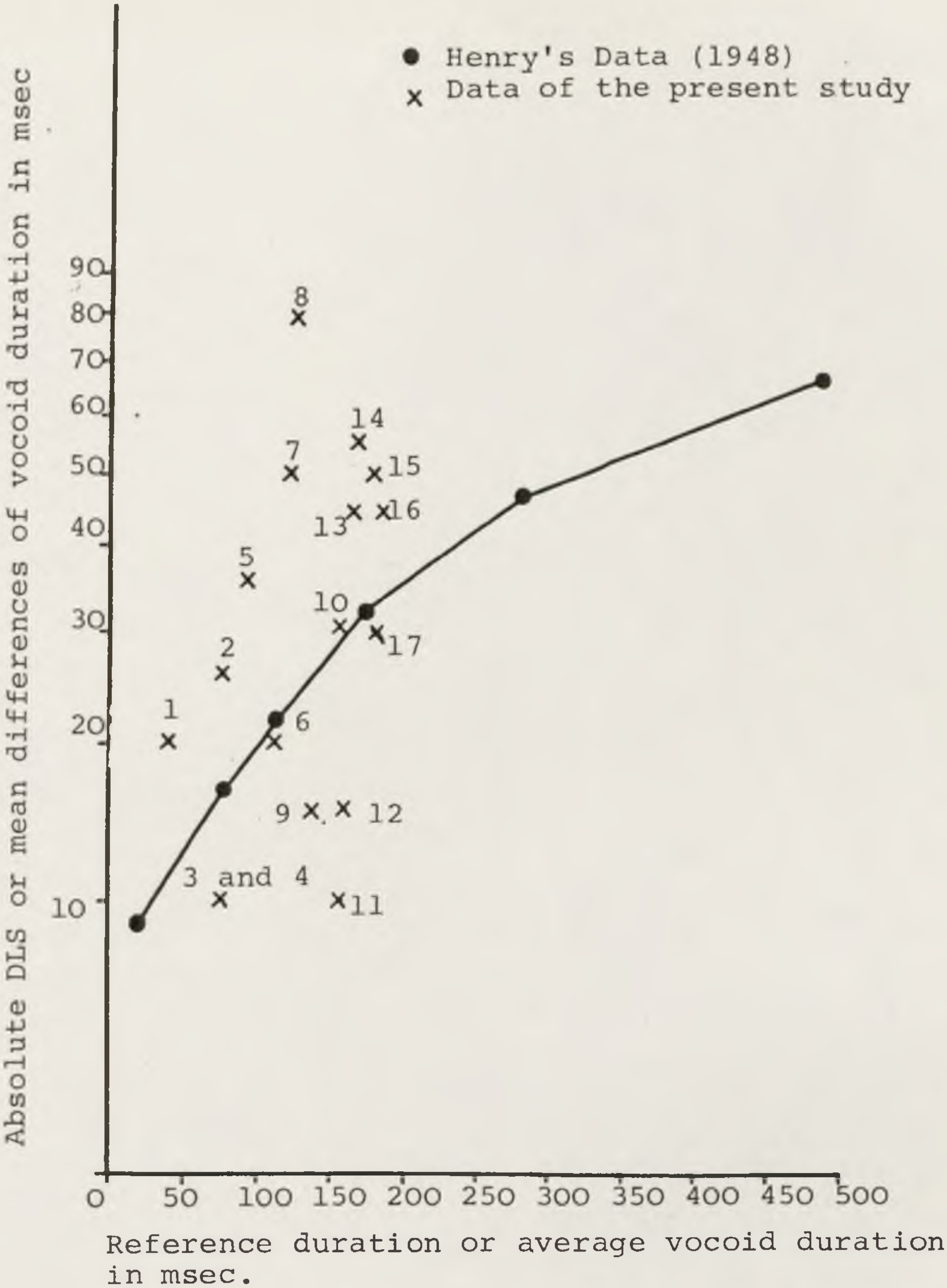


Fig. 4.15

Absolute DLS or mean differences of vocoid duration are plotted against reference duration or average vocoid duration on a semilogarthmic graph paper for a comparison between Henry's (1948) data for absolute DLS at different reference durations and the data of this study. The numbers correspond to the serial numbers of the sequences investigated as shown in table 4.8.

CHAPTER FIVE

MYODYNAMIC AND AERODYNAMIC INVESTIGATION OF VOWEL DURATION IN I.S.A.

5.1 Introduction and Aims

In this chapter the acoustic findings on vocoid duration in I.S.A. obtained in Chapter Four are subjected to a myodynamic and aerodynamic investigation. As we have seen in Chapter Three, the acoustic output, i.e. the speech sound waves observed in the acoustic stage are actually created in an earlier stage by the interactions of the myodynamic and aerodynamic conditions. Such a study, therefore, may shed light on three important areas of speech communication; (a) the acoustic structure of speech sounds, (b) the organization of speech production and (c) how (a) and (b) interact.

Four experiments were conducted, as described in this chapter, to establish the myodynamic and aerodynamic correlates of vocoid duration in I.S.A. i.e. to determine to what extent these myodynamic and aerodynamic correlates contribute to the acoustic variations of vocoid duration in I.S.A. in so far as the phonetic contexts specified in Chapter Four are concerned. (See

Section 4.1). Words were selected from those investigated in the acoustic stage (see Appendix 1) in such a way that they would comply with the general aims of the experimental investigation which can be specified as follows:

<u>Experiment 1</u> to investigate the myodynamic and aerodynamic correlates of intrinsic duration of vocoids in I.S.A.

<u>Experiment 2</u> to investigate the myodynamic and aerodynamic correlates of vocoid duration associated with differences of voicing and manner of articulation of the following contoid.

<u>Experiment 3</u> to investigate the myodynamic and aerodynamic correlates of vocoid duration associated with differences of place of articulation of the following contoid.

<u>Experiment 4</u> to investigate the myodynamic and aerodynamic correlates of vocoid duration associated with stress and intervocalic geminates.

Besides the myodynamic and aerodynamic measurements the reader will find, later in this chapter, that acoustic measurements concerning vocoids and contoids of some test words have also been included. The main objective in including these acoustic measurements here is to link the myodynamic and aerodynamic findings of this chapter to the acoustic findings of Chapter Four, on one hand, and, on the other hand, to see whether the acoustic durational differences found in Chapter Four show the same trends in the present experiments so that we may accordingly suggest adequate myodynamic and/or aerodynamic interpretations of these acoustic differences.

All myodynamic, aerodynamic and acoustic measures have been tabulated and subjected to a statistical treatment to see the level of significance of the differences between the compared data. A distinction will be drawn, later in Chapter Six, between differences which are statistically significant and those which are not only statistically significant but also above the threshold for perception (JNDs) of the differences concerned.

5.2 Experimental Methods

5.2.1 Airflow and Pressure

5.2.1.1 A Critical Survey and Aims

In recent years the study of airflow and pressure has played an important part in phonetic research. This stems partly from the fact that the investigation of these aerodynamic events may give insight into articulatory activities and timings. It has been shown for instance that voiced versus voiceless consonants can be distinguished on the basis of higher versus lower intraoral pressure and/or higher versus lower airflow rate and that both airflow rate and intraoral pressure can provide vital information concerning the glottal and supraglottal constrictions during the articulation of these segments, (Fant (1960), Malécot (1968 and 1970), Scully (1970 and 1979), Slis & Cohen (1969), Slis (1970), Lisker (1965), Isshiki & Ringel (1964) among others). It has also been shown that higher intraoral pressure is correlated with higher speech effort level, other things being equal (Hixon (1966)) and that higher subglottal pressure can be well correlated with stress (Ladefoged (1963)).

Klatt, Stevens & Mead (1968) studied airflow during speech and interpreted the patterns in terms of articulatory mechanism and timings and the manner in which the speech-generating mechanism is controlled.

They presented the following criteria for grouping consonants according to the properties of the flow traces assuming that: '... these groupings reflect established linguistic categories.' (op. cit., p.48). As for vowels they state that: 'Vowels have the least flow of any phone type (except for voiced stop consonants.)' (op. cit., p. 45).

1. /m, n/. The traces of these consonants are comparable to those of vowels in isolation.

2. /r, l, y, w/. The airflow traces of these consonants are similar to those of /m, n/ but with slightly less flow.

3. /h/. As for this consonant they state:

> 'This phone type has the greatest volume increment and has an airflow trace with a large broad peak.' (op. cit., p.48).

4. /<u>s, ʃ, f, θ</u>/. These consonants have airflow traces with double peaks which are probably: 'a consequence of the relative timing of laryngeal and articulator gestures.' (ibid). Klatt et al, associate these double peaks with the following articulatory manoeuvres with respect to the articulation of /f/:

> '... the upper teeth begin contact with the lower lip; the constriction that is formed causes a rise in mouth pressure, and as a result, vocal cords vibration ceases rather abruptly. The supraglottal articulator continues to constrict until flow resistance reaches a minimum value. The articulator begins to move away in anticipation of the next sound, thus lowering flow resistance. The airflow through the glottis increases, the vocal cords begin to approximate as a consequence of the reduced mouth pressure and the Bernoulli-effect pressure, and vocal-cord vibration begins. This glottal activity increases the total flow resistance, and the flow drops to a value characteristic of the vowel.' (ibid).

4. /<u>z, ʒ, v, ð</u>/. These consonants are similar to those

of group 3 except that airflow is reduced and the double peak is less pronounced:

> 'Since voicing continues through these sounds, there is a higher laryngeal resistance than there is for the voiceless fricatives, and hence a smaller airflow.' (ibid).

5. /b, d, g/. These consonants have, as they state:

> '... a flow trace indicating a burst release with a fast rise time and a small peak, followed by a rapid transition to airflow characteristic of the following vowel. The transient peak in flow is apparently a consequence of the sudden release of mouth pressure.' (ibid).

6. /p, t, k/. Klatt et al, state that this group:

> '... has a flow trace indicating a burst release with a fast rise time and a large peak followed by a slower return to airflow characteristic of the following vowel.' (ibid).

Nevertheless, Scully (1969) believes that certain practical difficulties as well as theoretical problems could be associated with the use of the mask and consequently with airflow measurements. Some of these difficulties and problems are listed below.

1. Adjusting the mask to fit differently shaped faces

and the difficulty of making the fit completely air-tight during speech.

2. The possibility that the mask may restrict jaw movement.

3. The possibility that the mask may reduce the auditory feedback to the speaker.

4. Some airflow traces may show ingressive airstreams before some plosive bursts and during some open vowels as shown by her data. Ingressive airflow during /k/ and /g/ is attributed by Isshiki & Ringel (1964, p.238) to:

> 'posterior movements of the tongue at the moment just prior to the release and the subsequent inflow of air into the enlarged oral cavity.'

For the purpose of this study airflow i.e. volume flow rate of air and intraoral pressure are considered in some detail and are taken to (a) give insight into the sound sources and hence the speech sound structure and (b) give information about myodynamic timing and control.

5.2.1.2 Instrumental Set-up

(a) Volume Airflow Rate

Volume airflow traces were obtained by means of a mask fitted to the subject's face; nose airflow and oral airflow were separated by a relatively rigid rubber partition and the mask was tightly pressed on the speaker's face to minimise and if possible prevent the escape of air in and out around the mask edge. Two Mercury flow heads type F100L each fitted with a Gaeltec pressure transducer type 8T (± 2 cm H2O) (a pneumotachograph device) were mounted in the mask, one in the upper part for nose airflow and the other in the lower part for the oral airflow. The outputs of both transducers were fed into a Gaeltec control unit and amplifier and then low-pass filtered at 12 dB octave with a cut off frequency of 50 Hz (in the aerodynamic speech analyser, see Sections 5.2.2.1 and figure 5.1.). Since nose airflow was not required in any of the four experiments because no nasals were investigated, it was only used for checking to ensure that there was no leakage through the rubber partition separating the nose from the mouth. An initial check is usually made by breathing in and out first through the nose only and then through the mouth only. Thus only the oral airflow was displayed on the mingograph traces as channel 2, synchronized with the other five traces used in the four experiments viz., area channel 1, intraoral pressure channel 3, electrical laryngograph signal channel 4, duplex oscillogram channel 5 and intensity H.P. filtered at 500 Hz channel 6. (See Figure 5.1 and Appendix 3).

(b) Intraoral Air Pressure

Traces of intraoral pressure were obtained by means of a polyethylene tube with an external diameter of about 3 mm and an internal diameter of about 2.5 mm. The tube was inserted in the mouth and was bent by heating in water to fit round the upper molars for experiments where front consonants were investigated. The open end of the tube pointed downwards across the air stream near the midline inthe oral-pharyngeal cavity. In this position as stated by Hardy (1965) spurious pressure readings are least likely to occur. On the other hand, for experiments where pharyngeal and uvular consonants were investigated another more flexible tube, having two holes at the end, was inserted through the nose with the open end as far into the pharynx as possible. However, no pressure traces could be obtained for the pharyngeals because, it seems the supraglottal constriction for [ħ] and [ʕ] are accomplished in the lower part of the pharynx.

A reference tube for intraoral pressure was also used the end of which was inside the mouth mask space. The pressure drop across the tongue constriction (ΔP) is measured as pressure difference between the tube behind the constriction and the tube reference in front of the constriction. See figure 5.1. The pressure of air was transmitted through these tubes to a Gaeltec pressure transducer type 3CT ($\pm$ 10 cm H2O). Since saliva and mucus could block the tube, it had to be cleared every two or three runs. The signals coming from the transducer propotional to pressure drop across

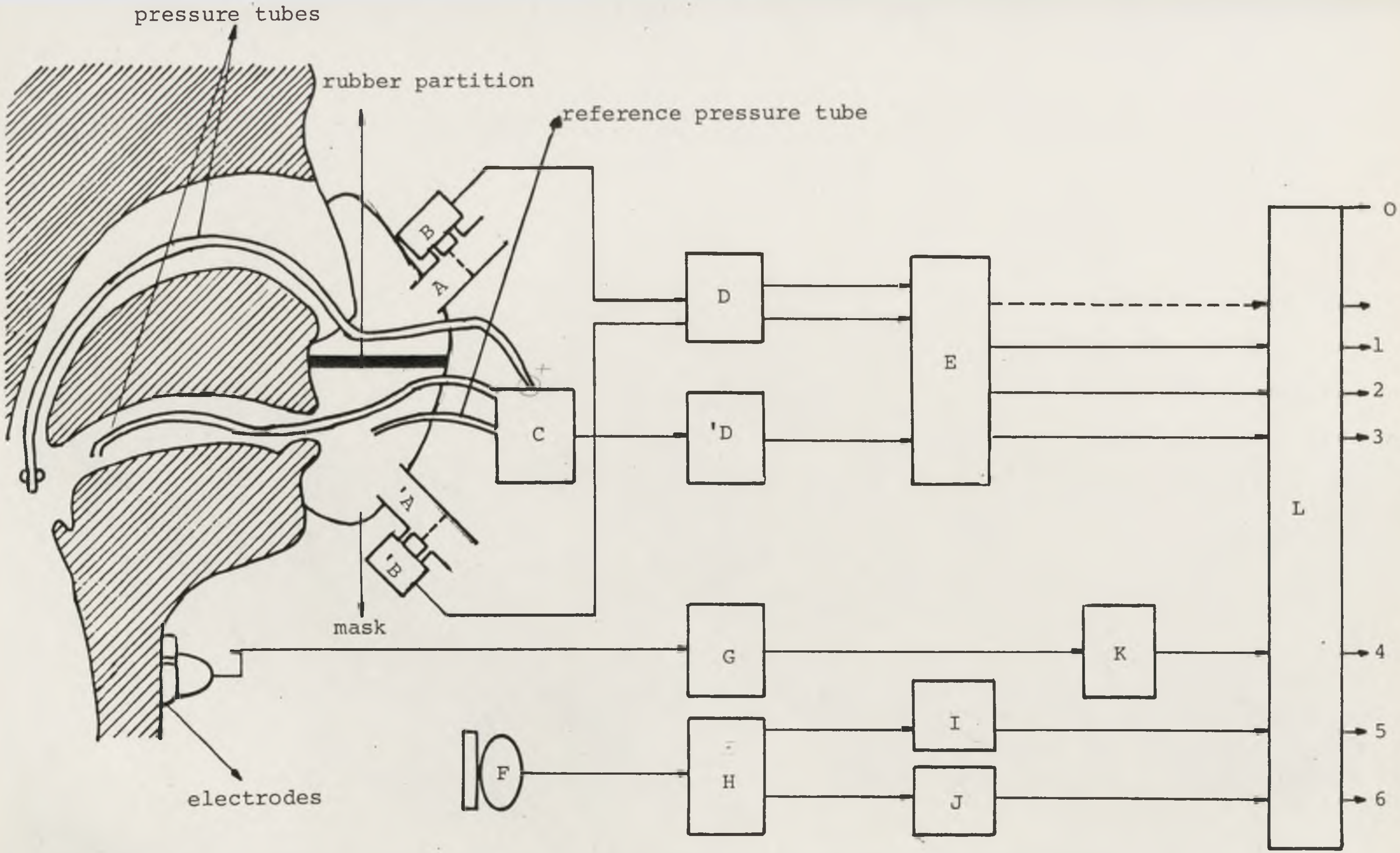


Fig. 5.1. Combined block diagram of instrumental set-up as used in different combinations in all four experiments.

A	Flowhead for nose airflow (Mercury)
B	Pressure transducer for noseflow head (Gaeltec)
'A	Flowhead for mouth airflow (Mercury)
'B	Pressure transducer for mouth flowhead (Gaeltec)
C	Pressure transducer for pressure tubes (Gaeltec)
D	Control unit and amplifier for air flow(Gaeltec)
'D	Control unit and amplifier for pressure(Gaeltec)
E	Aerodynamic speech analyser (R. Caley)
F	Microphone placed outside the mask (AKG type D19OE)
G	Electrical Laryngograph (UCL)
H	Tape recorder (Revox)
I	Transpitch (FO) meter + Duplex oscillogram (F-J)
J	Intensity meter (F-J)
K	Oscilloscope displaying laryngograph signal
L	Mingograph (Schonandar No.803)
----	Nose airflow used for checking only

0 Time marker
1 Area. Mingo. gain set at 4
2 Oral airflow. Mingo. gain set at $5\frac{3}{4}$
3 Intra oral pressure. Mingo. gain set at $2\frac{3}{4}$
4 Laryngograph
GX. Mingo. gain set at $1\frac{1}{2}$
5 Duplex oscillogram
Mingo. gain set at 3
6 Intensity H.P. filtered at 500 Hz
Mingo. gain set at 2

For real mingogram displaying the above channels see Appendix 3.

the constriction were fed into a Gaeltec control unit and amplifier and low pass filtered at 12 dB octave with a cut off frequency of 50 Hz (in the aerodynamic speech analyser. See Section 5.2.2.1 and Figure 5.1) and displayed by means of mingograph type Schonander No.803.

5.2.2 Area

5.2.2.1 Introduction and Aims

An aerodynamic method of inferring aspects of the speaker's myodynamic control is used in this study. For a constriction of the vocal tract: if u, the volume flow rate of air through the constriction, and ΔP, the pressure drop across it, are known, then A, the cross section area of the constriction, may be inferred, approximately, by means of the orifice equation $u = K.A.\sqrt{\Delta P}$ where K is an empirical constant (Warren & DuBois (1964)).

For the purpose of this study, the method is used to give, approximately, the timing of the smallest constriction area formed by the supraglottal articulators in the production of fricatives e.g. by the tongue and the denti-alveolar region of the palate in the production of [s] and [z]. The magnitude of the constriction at its smallest is also compared for some fricatives e.g. [s] and [z].

5.2.2.2 Instrumental Set-up

"Area" traces were obtained by means of the aerodynamic speech analyser; an analog computer device, designed and constructed by Mr R.W. Caley, Electric Instrument Design. This device accepts as input electrical signals proportional to u (volume airflow rate) and ΔP (pressure drop) and it gives as output an electrical signal proportional to $u/\sqrt{\Delta P}$. All the signals are low-pass filtered at 12 dB/octave with a cut-off frequency of 50 Hz and displayed by means of the mingograph on channel 1 (see figure 5.1). Since relative areas rather than absolute magnitude are of interest in this study, the constant K in the orifice equation is taken as 1.(1)

The "area" trace was used to locate the minimum value of constriction area, replacing the laborious sampling otherwise required. At the times of minimum area thus located, the relative magnitudes of constriction area were calculated from the calibrated traces of airflow and pressure transducer systems.

5.2.3 Electrical Laryngograph

5.2.3.1 A Critical Survey and Aims

Our first wish was to use Frøkjær-Jensen photo-electric glottograph (optical glottograph) (Frøkjær-

---

(1) To obtain a better estimate of the actual magnitude of cross-section area for an orifice, the "area" function obtained here should be multiplied by 1.27 (for volume flow rate of air in L/m and pressure drop in cm H_2O) to give area in sq mm, if the empirical constant in the Bernoulli equation is taken as 0.875 (Van den Berg et al 1957).

Jensen (1967 and 1968), FrØkjær-Jensen & Thorvaldson (1968)) to register the timing of glottal opening and closing gestures in relation to the opening and closing gestures of the supraglottal constriction but we could not get simultaneous glottographic traces for all the speech material included in the present experiments synchronized with the other five traces displayed on mingograms. This was largely due to the following:

(a) Technical difficulties concerning the use of the photo-electric-glottograph in conjunction with the mask for a relatively long time because the subject had to stabilize the mask in a fixed position on his face as efficiently as stabilizing the lamp projector of the photograph on his larynx and any movement from that fixed position could lead to a failure of either technique.

(b) Although we managed to get glottographic traces for some test words uttered in isolation, the bulk of our word material embedded in a carrier sentence rendered the use of this technique almost impossible. No attempt was made to use each technique independently of the other because this would have inevitably led to an inconsistent comparison of our data.

Nevertheless, since our main concern for the purpose of this study is to get information about the duration of the vocal folds adduction i.e. the duration of the phonatory state that is observed during the production of vocoids and not the glottal aperture observed during the production of the following and preceding contoids, we resorted to the use of the electrical laryngograph as an alternative since it provides, as stated by Fourcin & Abberton (1977, p. 313):

> 'useful information about the nature of vocal fold contact during phonation without in any way impeding the process of speaking.'

This technique has been given different names. Fabre (1957), who was the first to use it, calls it a glottograph. Frøkjær-Jensen (1968) calls it, a Fabre glottograph. Fourcin (1974) prefers to call it a laryngograph because:

> '... glottal area variations do not contribute substantially to its output.' (op. cit., p.318).

This technique has also been called electro-laryngography by Roach (1978a).

The electrical laryngograph used in this study is the one first designed by Fourcin & Norgate (1965) and developed by Fourcin & West (1968) at the Department of Phonetics and Linguistics, University College London, which is similar in concept to Fabre's (1957) instrument.

Fourcin & Abberton (1971) believe that the electrical laryngograph differs from the photo-electric-glottograph in that the output of the laryngograph is largely independent of the glottal aperture and almost totally dependent on the degree of vocal fold contact. Abberton (1972, p.69) also states:

> '... the wave form of its output, gives information about the frequency and mode of vibration of the vocal folds and it responds only when the vocal folds are in contact thus providing information, <u>not about glottal aperture</u> as with a glottograph, but about <u>the closed phase of the vibratory cycle</u>.'
> (Our emphasis).

Three types of wave form could be obtained from the electrical laryngograph as stated by Fourcin (1974):

1. Form of Lx or the rapid movement RM as suggested by Roach (1978a) representing the larynx vibration output. If there is any change in area or in the nature of vocal fold contacting area, from one cycle of vibration to another, there will be a corresponding change in Lx amplitude.

2. Form of Fx or Fo as suggested by Roach (op. cit.), which extracts Fo from the wave form and could serve in: 'producing a visual correlate of intonation.' (Fourcin, op. cit., p. 323).

3. Form of Gx or the gross movement GM as suggested by Roach (op. cit.) which can be represented by the whole trace.

The wave form of the gross movement Gx has been used in this study since:

> 'The Gx output is primarily a function of laryngeal adjustment prior to, during and after actual phonation.' (Fourcin, op. cit., p.321).

and that

> 'initial vocal fold adduction is associated with a small, sharp, precursive positive peak in Gx.' (ibid).

However, one should be cautious in interpreting the Gx traces since:

> 'other activity in the region of the larynx can contribute to it including swallowing, of course, and movements of the neck and head.' (ibid).

During our experimental sessions we managed to categorize the Gx trace into four levels associated with the mechanism of adducting and abducting the vocal folds as shown in figure 5.2. The highest level which we have called level 1 is associated with the complete closure of the glottis during the utterance of a glottal stop. Level 2 is associated with the phonatory state of vocal folds that is observed during the production of vowels. Level 3 is associated with the phonatory state of vocal folds that is observed during the production of voiced consonants. Level 4 is associated with the glottal state

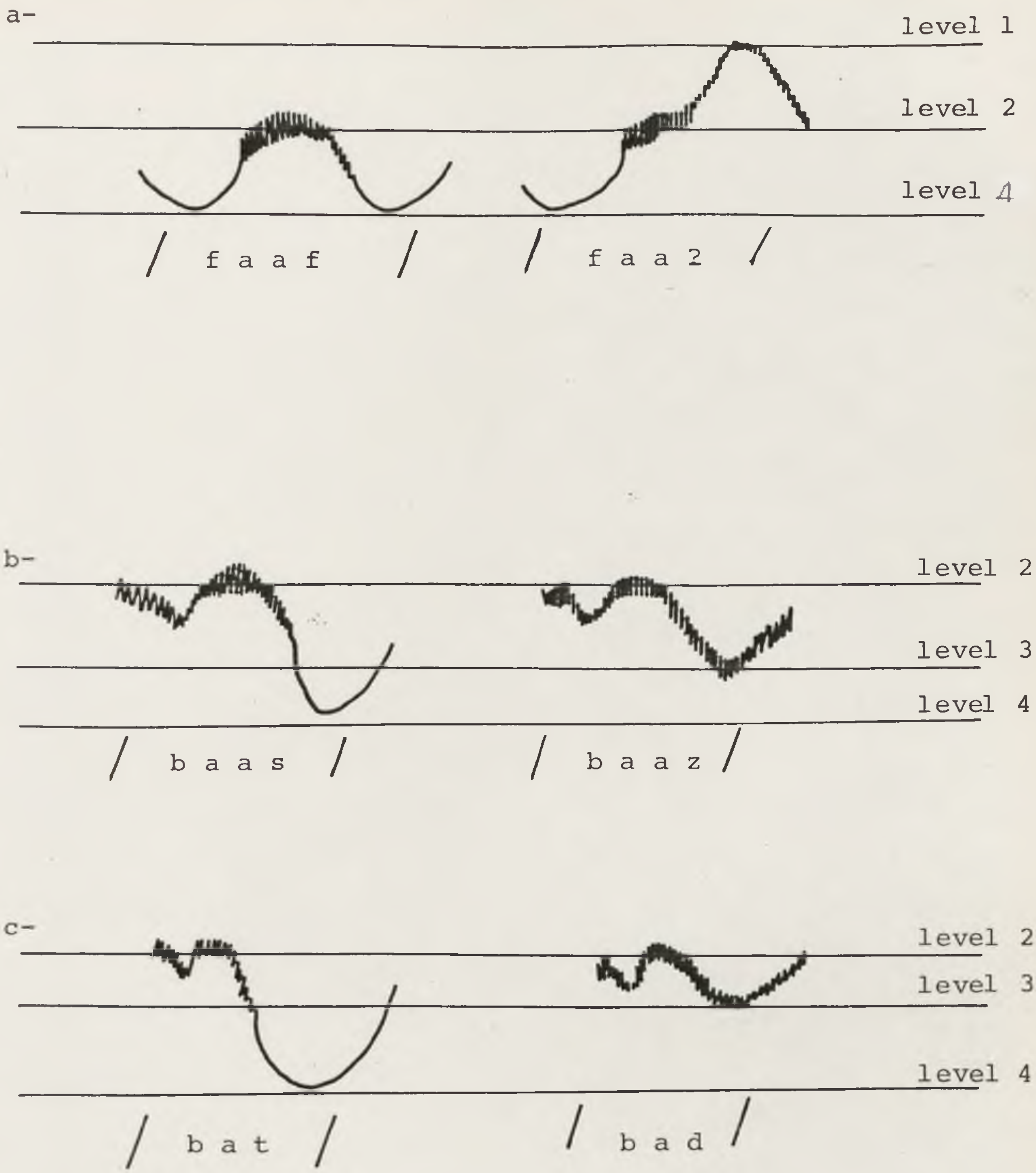


Fig. 5.2

Laryngograph traces based on real tokens of laryngograms showing different levels associated with the mechanism of adducting and abducting the vocal folds. Notice how levels 3 and 4 vary according to the place and manner of articulation of the consonant in question.

that is observed during the production of voiceless consonants. Level 3 and 4 are not always distinct and they vary according to the manner and place of articulation of the consonant in question.

These findings are partially supported by other studies. Roach (1978a) tested the Gx trace of the laryngograph by connecting its output to a laboratory computer and a signal averaging program. Figure 5.3 shows average Gx produced for 50 repetitions of [aʔ] and [a] where the vowel in the latter case was terminated by opening the glottis. From this figure one could understand that the peak of Gx could be associated with a complete closure of the glottis during the utterance of glottal stop, the voicing ripples could well represent the phonation observed during the utterance of vowels and the trough could be associated with the glottal opening. Odisho (1975) made a comparison between glottographic and laryngographic traces for some utterances. He found as shown in figure 5.4 that the glottal aperture is represented by a peak in the glottographic trace and by a corresponding trough of the laryngographic trace for the segment [t^h]. He states that the dip of the laryngographic trace:

> '... almost certainly, represents great resistance due to the loss of contact between the vocal folds which in its turn means an opening of the glottis.' (op. cit., p. 165).

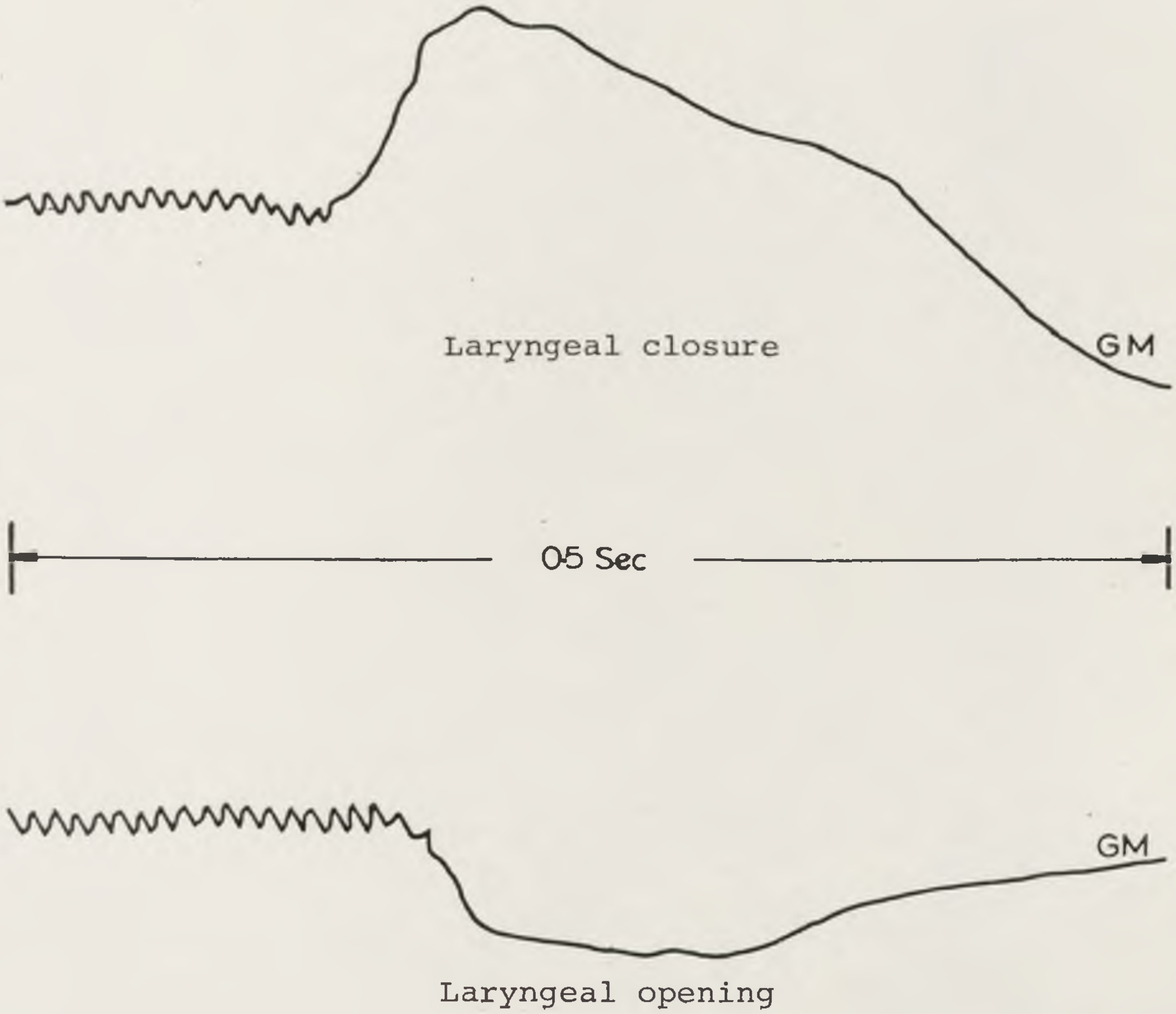
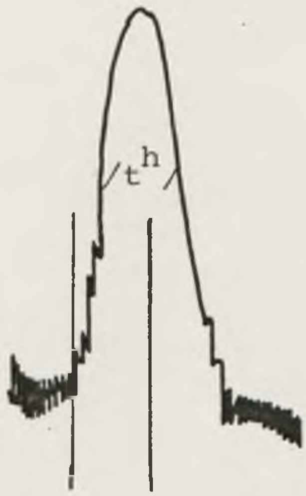


Fig. 5.3 *Average GM traces for 50 repetitions of [aʔ] and 50 of [a]. The vowel in the latter case was terminated by opening the glottis.

* After Roach (1978a)



a-

b-

Fig. 5.4 *Traces based on real tokens of a- glottograms, b- laryngograms for /t^h/ in intervocalic position. The vertical lines mark the closing and opening gestures of the supra-glottal structure.

*After Odisho 1975

It is still not certain, however, what factors actually bring about such variations in the Gx trace. Nevertheless, Roach (1978a) suggests two hypotheses as to why the Gx trace usually shows such levels based on laryngograph studies and direct observation of the larynx by fiberoptic methods:

1. The vertical displacement of the larynx strongly affects the Gx trace and:

> 'larynx raising will cause a rise in the trace and larynx lowering will depress the trace.' (op. cit., p.269).

2. In consequence he states:

> 'laryngeal closure will cause laryngeal elevation, while glottal opening at the end of phonation may bring about a slight lowering of the larynx.' (ibid).

To sum up, the above findings do not necessarily imply that the laryngographic Gx trace could give the same information concerning the glottal closure and aperture provided by the photo-electric-glottograph. However, it follows from the discussion above that the Gx trace can provide substantial information concerning the <u>timing</u> of the adducting and abducting gestures of the vocal folds in relation to the <u>timing</u> of the closing and opening gestures of the supraglottal constriction.

This method is adopted in section 5.3.4.

5.2.3.2 Instrumental Set-up

Laryngograph Gx traces were obtained by means of electrodes placed on both sides of the larynx. One electrode transmits a signal provided by an oscillator. The signal is picked up by the other electrode placed on the other side of the larynx and fed into a detector. The detector and the ancillary circuitry measure the attenuation of the signal between the electrodes. The output was set at AGC to give Gx traces displayed by means of the mingograph as channel 4 (see figure 5.1).

5.2.4 Instrumental Set-up for Acoustic Data

Simultaneous acoustic data for the same tokens were obtained by means of a duplex oscillogram using a Frøkjær-Jensen transpitch (Fo) meter and intensity H.P. filtered at 500 Hz using a Frø kjær-Jensen intensity meter. An AKG microphone of the type D190E was placed outside the mask and the signal from this microphone was fed into magnetic tape recorder, Revox type A77 used with an Ampex high frequency tape type PRT 1200, at a speed of 19 cm/s. Recording was made on channel 1 mono. Input was at NAB Mic 4+. The output was set at 8¾. The output from the Revox was fed into the intensity and transpitch (Fo) meters. The input to the transpitch (Fo) meter was set at 12 o'clock. The low-pass filter was at

120 Hz and the high pass filter was out (not used). The male setting was used and the zero line knob was set at fully counter-clockwise. The duplex oscillogram on the transpitch (Fo) meter was set at 12 o'clock. The input to the intensity meter was set at 26 dB. The smoothing time was 10 msec and the calibration was set at log. The duplex oscillogram was displayed on channel 5 and intensity H.P. filtered at 500 Hz was displayed on channel 6 on mingograms, synchronized with the other four traces (see figure 5.1).

5.2.5 Subject's Background and Selection of Material

In order to maintain consistent processing of our data throughout this study, the author acted as the subject of all the present experiments and the reader is referred to Section 4.2.2 for details of subject's background..

Selective lists of test words were chosen from those investigated in Chapter Four in such a way that they would comply with the aims of the present experiments, specified in Section 5.1. The reader is also referred to Section 4.2.1 for details of the method of saying the words and number of tokens. The carrier sentence was slightly modified in the present experiments; the fricative following the target word was replaced by the approximant [w] by inserting the word /wu/ immediately after the target word and the carrier sentence has become, /'ʔikitbuu- wu sit mar'raat/, "Write - and six times". It is judged that, with this slight modification only, the overall tempo and intonation, which were meant to be similar to those of the former sentence, were not affected. The aim of this modification was to be able to locate a point which could be taken as a word boundary on area, airflow and pressure traces. If the target word were to terminate in a fricative and the sound following it were also a fricative, as in the former sentence, it would be very difficult to locate that point, on one hand, and, on the other hand, no reliable measurement of the word final contoid could be made on these traces because the traces of both contoids would be merged into each other.

5.3 Segmentation and Measurement Criteria

5.3.1 Introduction

In accordance with the discussion of the experimental methods used to investigate the myodynamic and aerodynamic activities in the vocal tract during speech, we present criteria for segmenting and measuring particular segments and utterances based on the traces of airflow, pressure, area and laryngograph Gx. We have established certain points on these traces which can be taken to represent the initiation and cessation of certain articulatory events, and by reference to which reasonable myodynamic and aerodynamic measurements can be made.

Nevertheless, it is to be emphasized that this method is not direct observation of articulator movement as cineradiography is and it represents only rough approximation to the myodynamic (articulatory) and aerodynamic events being investigated.

Simultaneous measurements of acoustic timings have also been made for the same tokens on traces of duplex oscillograms and intensity H.P. filtered at 500 Hz following the same segmentation and measurement criteria as those presented in Chapter Four (see Section 4.2.5.2).

All myodynamic (articulatory) and acoustic measurements were made in msec using the same Rabone Chesterman ruler No.64R.

5.3.2 Minimum Cross-sectional Area of Constriction

According to the method of inferring the timing of the smallest constriction area formed by articulators in the production of fricatives (see Sections 5.2.2.1 and 5.2.2.2), the dip of the area trace is taken to indicate the moment of the minimum value of constriction area for fricatives. The relative magnitudes of constriction area were calculated at the times of minimum area thus located from the calibrated traces of airflow and pressure. Figure 5.5 (a) indicates the time of a minimum value of

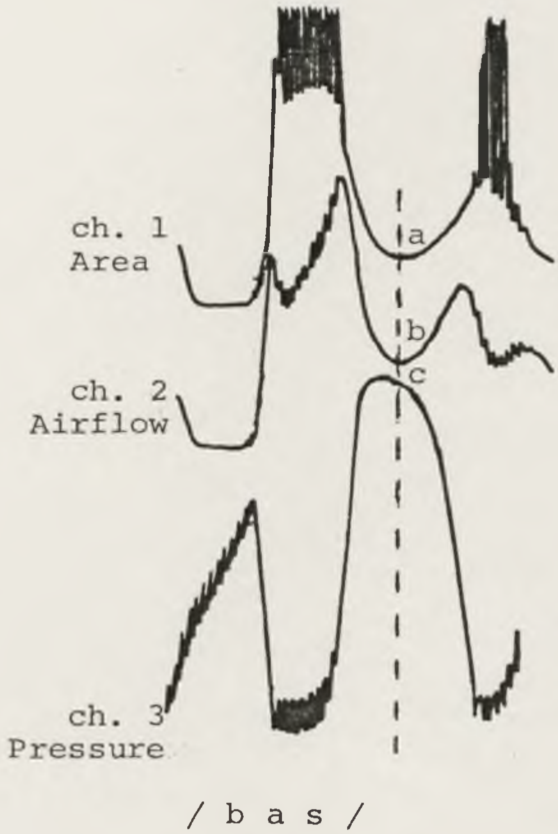


Fig. 5.5

Mingogram of the word /bas/ showing the criteria of segmenting and measuring Ac min., the minimum cross-sectional area of constriction, inferred from airflow and pressure measurements. a corresponds in time to Ac min., b corresponds to the value of Uo,volume airflow rate, at that time, c corresponds to the value of Po, intraoral pressure, at that time.

Ac (minimum cross-sectional area of constriction) for the segment [s]. b is the corresponding point on the airflow trace representing the value of Uo (volume airflow rate) at the time of a. c is the corresponding point on the pressure trace indicating the value of Po (intraoral pressure) at the time of a. The relative magnitude of Ac at a is calculated by the value of u at b divided by the value of $\sqrt{\Delta P}$ at c.

To find out whether the dip of the area trace coincided with the minimum value of $u/\sqrt{\Delta P}$ the accuracy of the area trace was checked by the following procedure.

Different points were selected at random on the area trace labelled d, e, f, g besides the point a at the dip for the segment [s] in /das/ and /bas/ and [z] in /baz/ as shown in Figure 5.6 and pressure and airflow were measured at these time points. Values of constriction area were calculated at these points. It was found, as shown in Table 5.1, that a gives the minimum value in all cases tested.

During this procedure we also discovered that (a), the point in time at Ac min., always coincides with (b), the point in time of Uo min., (the dip of airflow trace), for the examples tested (see Figures 5.5 and 5.6). Hence we took the dip of the airflow trace to indicate Ac min. for the back contoids for which no intraoral pressure traces

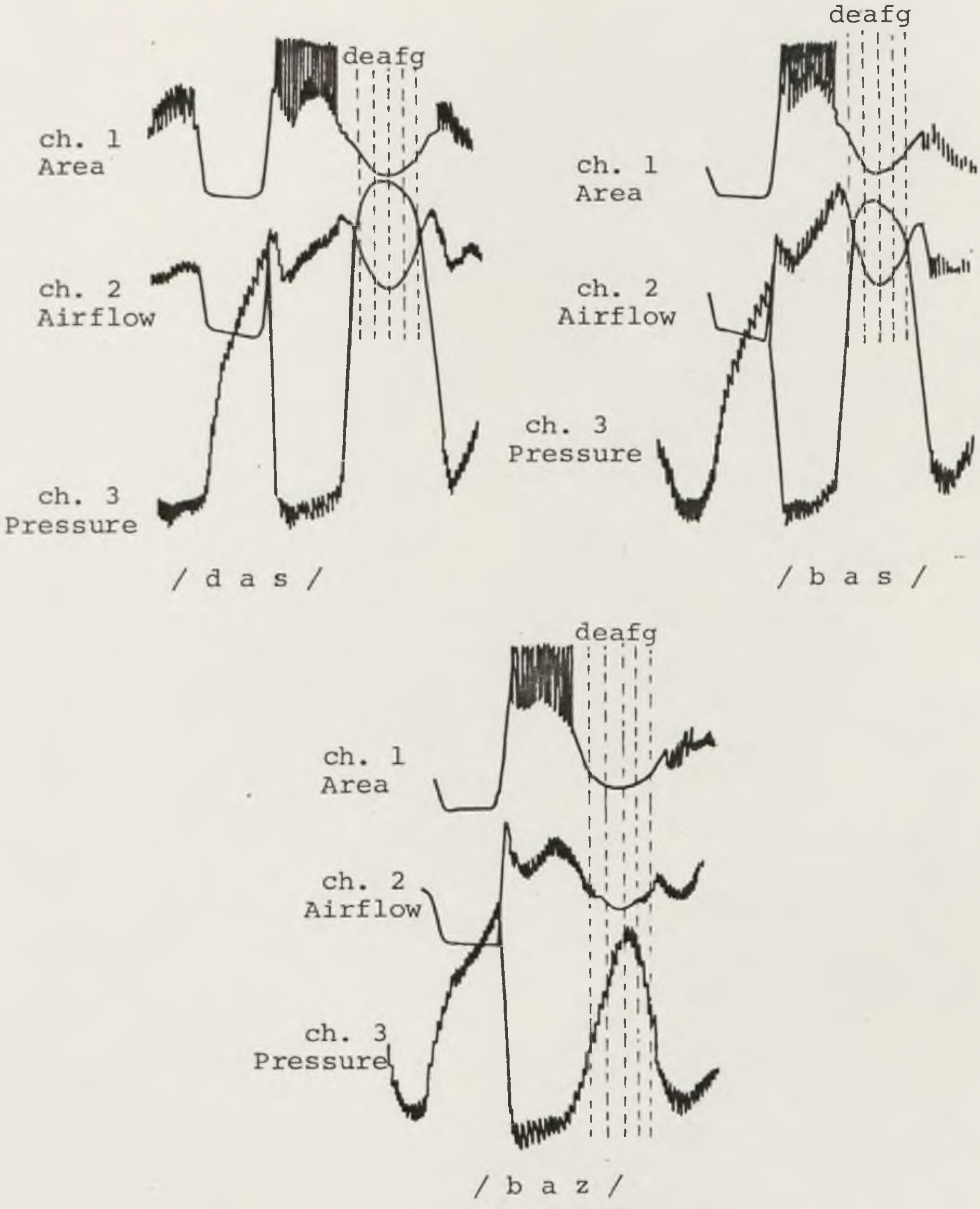


Fig. 5.6

Mingograms of the words /das/, /bas/ and /baz/ showing how the accuracy of the area trace is checked. d, e, f and g are points in time on the area trace. a corresponds in time to the minimum of the area trace. Values of Uo and Po are measured at corresponding points on airflow and pressure traces. Values of area constriction are calcualted at these points and shown in table 5.1. a is found to have the minimum value of $u/\sqrt{\Delta P}$ in all cases.

Table 5.1 Results of calculating Ac at the points in time of d, e, a, f and g on area trace by dividing values of Uo by values of $\sqrt{\Delta P}$ at corresponding points in time on airflow and pressure traces. (a) is found in all cases to have the minimum of Ac.

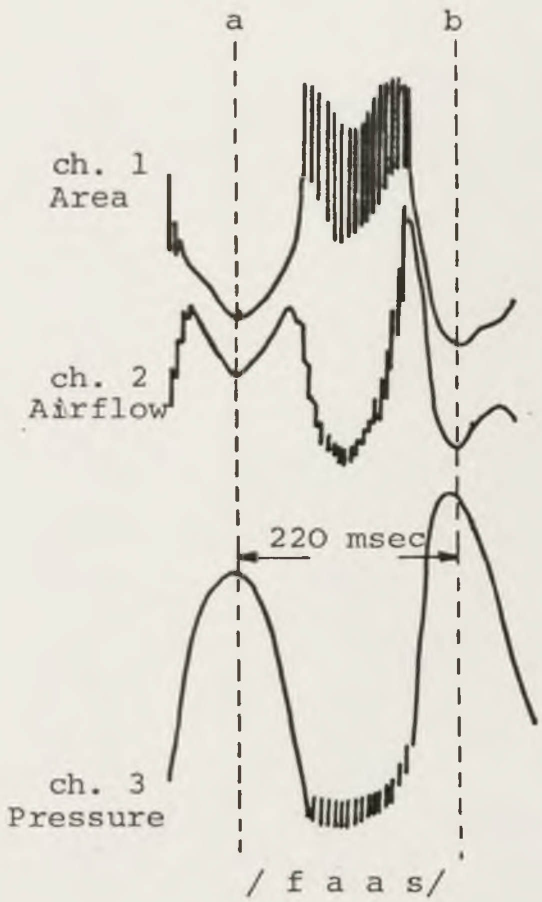
Utterances	d	e	a (the dip)	f	g
/das/	4.3	1.7	1.5	1.8	4.0
/bas/	4.8	3.0	2.3	2.9	4.2
/baz/	5.8	2.1	1.7	2.0	3.1

could be obtained and for which, consequently, no Ac measurements could be inferred. These criteria of Ac minimum (or Ub minimum for back contoids) have been used for measuring the myodynamic timing as we shall see in the following section.

5.3.3 Myodynamic Timing

What we mean by myodynamic timing of a word in this study is the duration between the myodynamic (articulatory) events surrounding (preceding and following) the intervening vocoids in monosyllabic words and certain syllables of bisyllabic words e.g. the time between the release moment of an initial plosive and the minimum cross-sectional area of constriction for a final fricative. Here, we have two objectives; firstly to see whether different myodynamic timings in executing the constriction of the following contoid correspond to different acoustic durations of the preceding vocoid, secondly, as a solution to the problem of establishing points word-initially and word-finally which may serve to indicate word boundaries.

For both initial and final fricatives the dip of the area trace corresponding to Ac minimum is taken as the point in time for measurements. As shown in Figure 5.7 a b indicates the myodynamic timing in msec for the monosyllabic word /faas/. For initial plosives the point in time at peak pressure is taken to indicate the occlusion



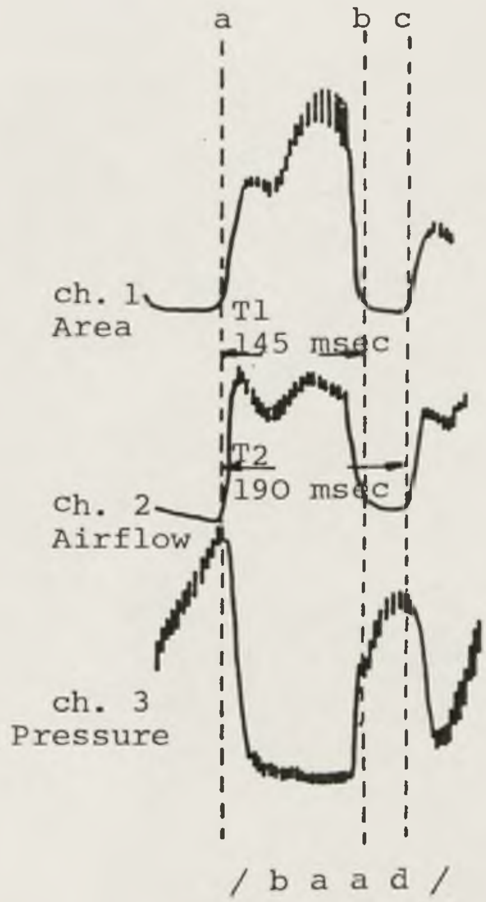


Fig. 5.7

Mingogram of the word /faas/ showing the criteria for segmenting and measuring myodynamic timing when the initial and final contoids are fricatives - a and b correspond in time to the minimum of the area trace and hence to the minimum cross-sectional area of constriction. Time between a and b represents the myodynamic timing.

Fig. 5.8

Mingogram of the word /baad/ showing the criteria for segmenting and measuring myodynamic timing when the initial and final contoids are plosives. a corresponds in time to the occlusion offset of the initial contoid. b corresponds in time to the occlusion onset of the final contoid. c corresponds in time to the occlusion offset of the final contoid. T1 is the myodynamic timing between a and b. T2 is the myodynamic timing between a and c. T2-T1 = occlusion duration of the final contoid.

offset of the initial contoid which always coincides with the sudden rising of the area and airflow traces from near the baseline. For final plosives two points in time have been established as shown in Figure 5.8; b indicates the time of the occlusion onset of the final contoid as defined by the area trace where it suddenly goes down to near the baseline, c indicates the time of the occlusion offset of the final contoid as defined by the peak pressure which coincides with the sudden rising of the area and airflow traces from near the baseline. a b gives T1 in msec and a c gives T2 in msec.

5.3.4 Duration of Vocal Folds Adduction

Measurements of the duration of the vocal folds adduction characteristic of vocoids were made on laryngograph Gx traces channel 4 (see Sections 5.2.3.1 and 5.2.3.2). A threshhold value was arbitrarily set at 3 mm from the maximum value of the Gx trace level 2 (see Figures 5.2 and 5.9). This point was located at the peak of the voicing ripple. Duration measurements in msec were made between points in time where the Gx trace crosses the threshhold value.

5.3.5 Myodynamic Duration of Supraglottal Constriction

Measurements of myodynamic duration of supraglottal constriction were made on the area trace channel 1. For

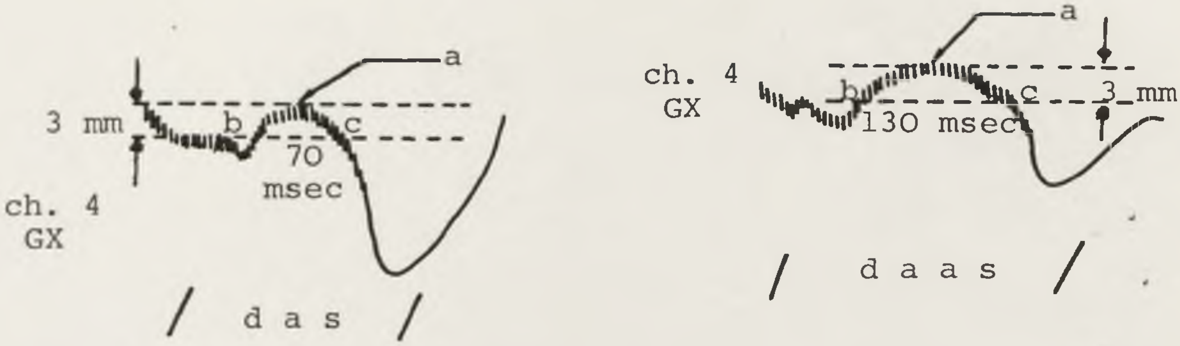


Fig. 5.9

Laryngograms of the words /das/ and /daas/ showing the criteria for segmenting and measuring the duration of V.Fs adduction on GX trace. a corresponds in time to the highest point on level 2 (see section 5.2.3.1). b c is a threshold value arbitrarily set at 3 mm below a. Time between b and c is taken to represent the duration of V.Fs adduction for /a/ and /aa/ in /das/ and /daas/ respectively.

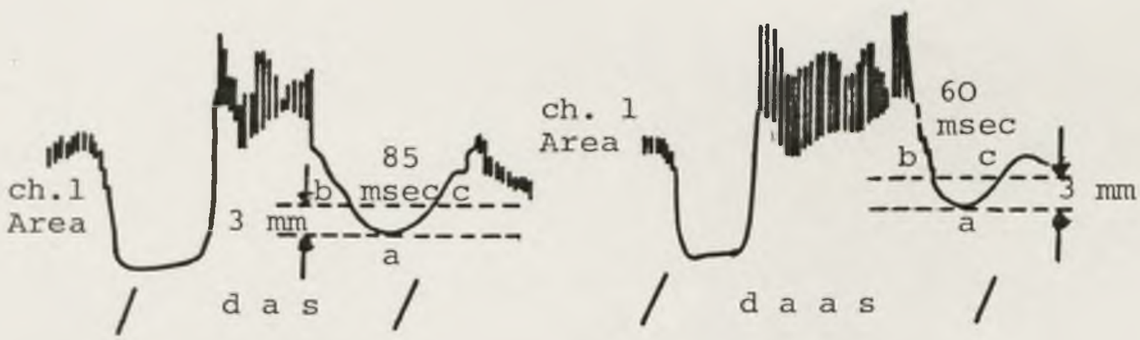


Fig. 5.10

Mingograms of the words /das/ and /daas/ showing the criteria for segmenting and measuring the myodynamic duration of the supraglottal constriction on the area trace ch. 1. a corresponds in time to the minimum of the area trace. b c is a threshold value arbitrarily set at 3 mm above a. Time between b and c is taken to represent the myodynamic duration of the supraglottal constriction for /s/ in /das/ and /daas/ respectively.

fricatives a threshhold value was arbitrarily set at 3 mm above the dip of the area trace. Duration measurements were made in msec between points in time where the area trace crosses the threshhold value and these are taken to represent the myodynamic duration of supraglottal constriction of fricative contoids as shown in Figure 5.10.

For plosives, constriction duration measurements were arbitrarily made by subtracting T1 from T2 (see Section 5.3.3 and Figure 5.8).

5.3.6 Acoustic Measurements of Contoid and Vocoid Duration

Acoustic duration of vocoids were made in msec on the trace of intensity H.P. filtered at 500 Hz with the threshhold value set at 26 dB channel 6. (For more details of our criteria of segmentation and measurement see Section 4.2.5.3).

Acoustic duration of the following contoid were made in msec on the duplex oscillogram, channel 5. For fricatives measurements were made from frication noise onset where the trace suddenly rises above the baseline to frication noise offset where the trace suddenly goes down to the baseline again.

For plosives measurements were made from acoustic closure onset where the trace suddenly goes down to the baseline to acoustic closure offset where the trace suddenly rises.

5.3.7 Statistical Treatment of the Data

All the myodynamic, aerodynamic and acoustic results were subjected to the same statistical test of the Mann-Whitney U test to assess the level of significance of the differences between the measurements compared. The same levels of significance as specified in Chapter Four were used in the present experiments; two asterisks indicate that the difference is statistically very significant at $p \leq 0.05$; one asterisk indicates that the difference is significant at $p > 0.05$ and $p \leq 0.07$; (-) indicates that the difference is not significant at $p > 0.07$. For more details of this statistical treatment see Section 4.2.7.

5.4 Results

All the myodynamic, aerodynamic and acoustic measurements for the two sets of tokens being compared, as well as the average values with their corresponding U and probability values are arranged in tables sub-divided in accordance with the general dims specified in Section 5.1.

A full discussion of the results of these tables in conjunction with the results obtained in Chapter Four will be made in Chapter Six. In this chapter, however, we shall only note briefly what results are shown by these tables.

5.4.1 Intrinsic Duration

Tables 5.2.1 and 5.2.2 deal with the myodynamic and aerodynamic correlates of intrinsic duration of vocoids in I.S.A.

Table 5.2.1 consists of eight items comprising myodynamic, aerodynamic and acoustic measures of monosyllabic minimal pair words containing open versus close vowels (short and long) and shows the following results:

1. Item 1 shows very significant differences in myodynamic timing between open versus close vowels, where p value is at 0.004 for long vowels and at 0.026 for short vowels, suggesting that the execution of the constriction of the contoid following open vowels is delayed relative to that for close vowels by 25 msec in /daas/ versus /diis/ and by 15 msec in /das/ versus /dis/.

2. Item 2 shows that the duration of vocal folds adduction is very significantly longer for open vowels than for close vowels; this is consistent with item 1 in suggesting that the vocal folds abduction is delayed in /daas/ by 20 msec relative to that in /diis/ and by 25 msec in /das/ relative to that in /dis/.

3. Item 3 shows no significant differences in the myodynamic duration of the supraglottal constriction.

4. Items 4 and 5 show no striking differences in the

aerodynamic correlates. Only item 5 shows significant difference in intraoral pressure in /daas/ versus /diis/ whereas no significant difference is shown to occur for /das/ versus /dis/; nor is there any significant differences in airflow between the same tokens in question as suggested by item 4.

5. Item 6 suggests that the final fricative [s] appears to have the same minimum cross-sectional area of constriction regardless of contexts in both /daas/ versus /diis/ and /das/ versus /dis/ i.e. no significant differences in the magnitude of the constriction at its smallest.

6. In item 7 the acoustic durations of vocoids show the same trend as found in Chapter Four (see Section 4.3.1) i.e. open vowels are very significantly longer than close vowels for /daas/ versus /diis/ and /das/ versus /dis/.

It is worth observing that thelonger acoustic duration of open vowels coincides with the longer myodynamic timing for words having open vowels and the longer duration of vocal folds adduction of vocoids for open vowels. This indicates as shown in Figure 5.11 that the delay of executing the constriction of the fricative following open vowels might have its effect on prolonging the acoustic duration of the preceding vocoid.

Table 5.2.1 [1] Myodynamic, aerodynamic and acoustic measures of monosyllabic minimal pair words containing open versus close vowels (short and long)

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Myodynamic timing in msec between occlusion offset of the initial plosive and Ac minimum of the final fricative									
/daas/	205	210	215	205	195	185	200	1	** 0.004
/diis/	175	155	180	160	185	185	175		
/das/	185	205	185	170	215	195	190	4	** 0.026
/dis/	180	165	180	185	165	160	175		
2. Duration of vocal folds adduction in msec									
/daas/	150	140	130	150	150	115	140	4.5	** less than 0.042
/diis/	125	115	130	100	130	110	120		
/das/	85	90	95	90	95	80	90	0.5	** less than 0.004
/dis/	65	60	70	70	80	60	65		
3. Myodynamic duration of supraglottal constriction of the final contoid in msec									
/daas/	60	60	60	60	45	45	55	14	(-) 0.588
/diis/	50	70	55	60	55	70	60		
/das/	80	85	85	95	100	100	90	9.5	less than 0.240
/dis/	95	90	100	100	100	100	95		

(1) For details of segmentation and measurement criteria the reader is referred to all subsections of section 5.3, which apply for all the tables included in this chapter.

Table 5.2.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
4. Uo at Ac minimum in L/m of the final contoid (fricative)									
/daas/	8	11	8	5.5	7	11	8.4	14	(-) 0.588
/diis/	5	7	11	6	11	7	7.8		
/das/	4.5	9	5.5	6	11	12	8	11.5	(-) less than 0.394
/dis/	8	8	12	12	10	9	9.8		
5. Po at Ac minimum in cm H_2O of the final contoid (fricative)									
/daas/	14.5	14.5	13	13.5	16	15	14.4	6	* 0.064
/diis/	15	16.5	15	15	15	16.5	15.5		
/das/	16	14.5	15	14.5	15	15	15	7.5	(-) less than 0.132
/dis/	17	16	14	15.5	17.5	16.5	16		
6. Ac minimum $(u/\sqrt{\Delta P})$ of the final contoid (fricative)									
/daas/	2.109	2.889	2.219	1.497	1.750	2.840	2.226	12	(-) 0.394
/diis/	1.290	1.515	2.840	1.549	2.840	1.723	1.959		
/das/	1.125	2.363	1.420	1.576	2.840	3.098	2.070	13	(-) 0.424
/dis/	1.455	2.000	3.207	3.048	2.390	2.216	2.386		

Table 5.2.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
7. Acoustic duration of vocoids in msec									
/daas/	185	195	180	175	170	170	180	1	** 0.004
/diis/	155	155	165	135	170	160	155		
/das/	130	130	125	115	140	130	130	0	** 0.002
/dis/	110	100	110	110	110	100	105		
8. Acoustic duration of the final contoid (fricative) in msec									
/daas/	95	80	70	95	105	105	90	14.5	(-) less than 0.7
/diis/	65	70	45	90	110	110	80		
/das/	130	155	130	145	140	130	140	10	(-) 0.240
/dis/	150	140	140	135	170	150	145		

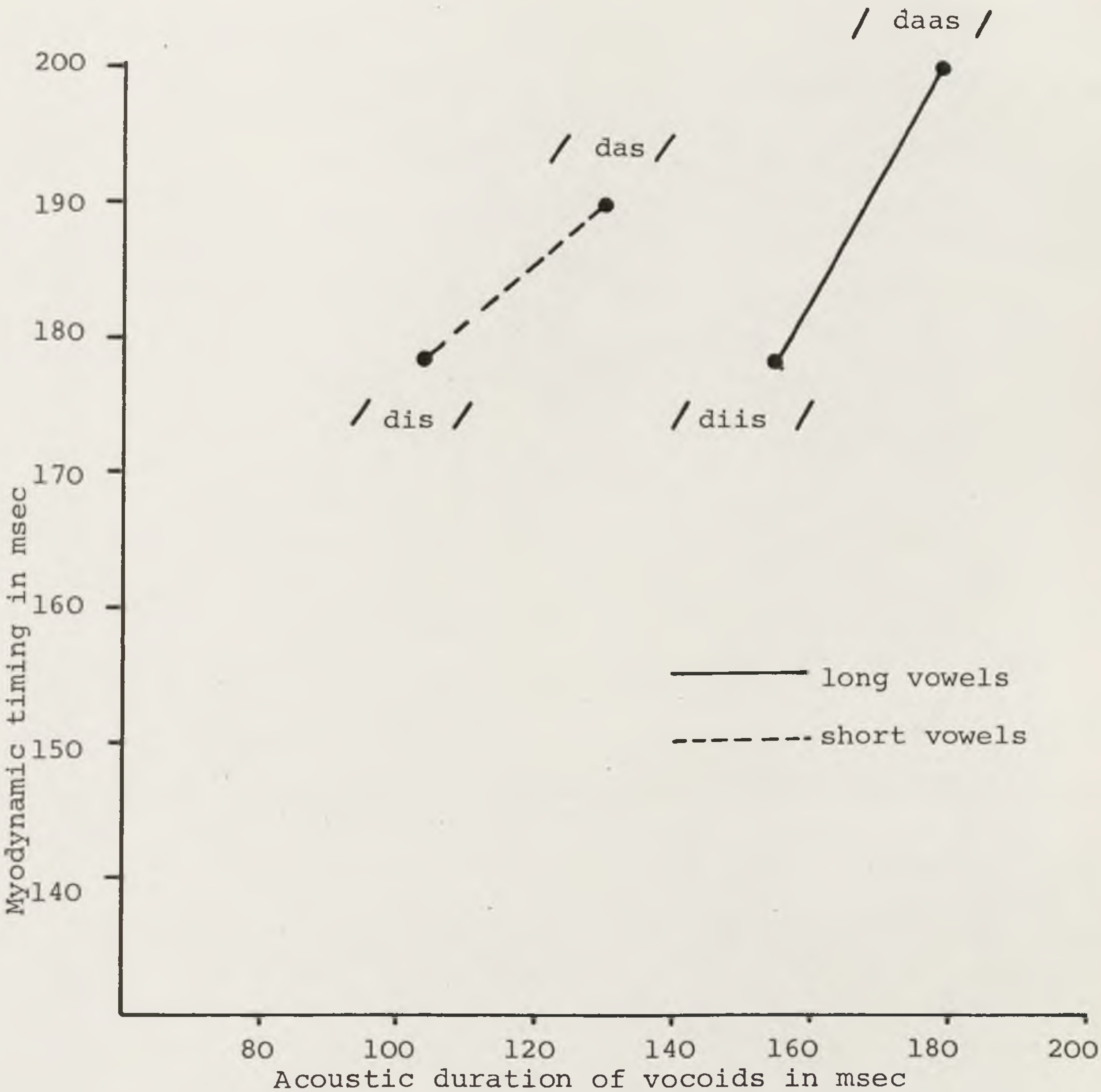


Fig. 5.11

Average values of myodynamic timing in msec plotted against average values of acoustic duration of vocoids in msec in minimal pair words containing open versus close vowels (long and short).

7. The acoustic duration of the final contoid [s] is shown by item 8 to have no significant differences for both /daas/ versus /diis/ and /das/ versus /dis/ which is in striking agreement with item 3.

Table 5.2.2 contains the same items as Table 5.2.1 rearranged so as to show contrasts between <u>long versus short vowels (open and close)</u>. It shows the following results:

1. Item 1 shows no significant differences in myodynamic timing for /daas/ versus /das/ and /diis/ versus /dis/ despite the fact that phonologically speaking /aa/ is distinctively longer than /a/ and /ii/ than /i/. This is consistent with the non-significant differences of the word overall acoustic timing shown by item 9.

2. Despite the non-significant differences in myodynamic timing mentioned above, the duration of vocal folds adduction is shown by item 2 to be very significantly longer for long vowels than for short vowels. It is 50 msec longer in /daas/ versus /das/ and 55 msec in /diis/ versus /dis/.

3. Item 3 shows an opposite trend to that of item 2; the myodynamic duration of the supraglottal constriction of the final contoid, which is the segment [s] in all cases, is very significantly longer when following short vowels than when following long vowels. It is 35 msec longer in both /daas/ versus /das/ and /diis/ versus /dis/.

Considering the fact that the myodynamic timing of the compared words is the same as shown by item 1, these reversed trends of timing of items 2 and 3 strongly suggest that the durations of the supraglottal constriction and the vocal folds adduction are compensating each other in the monosyllabic minimal pair words in question.

4. Item 4 and 5 show no significant differences in the aerodynamic correlates. Neither airflow nor intra-oral pressure is shown to be significantly different for both minimal pairs.

5. The cross-sectional area of constriction for the final fricative [s] is shown by item 6 to be the same regardless of the compared contexts in question.

6. Item 7 shows that the acoustic duration of vocoids is very significantly longer for long vowels than for short vowels (open and close). This is consistent with the same trend as found in Chapter Four (see Section 4.3.1).

7. Item 8 shows an opposite trend to that of item 7; the acoustic duration of the final contoid [s] is significantly longer when it is preceded by a short vowel than when it is preceded by a long vowel. It is 50 msec longer in /das/ versus /daas/ and 65 msec longer in /dis/ versus /diis/. This is consistent with the same opposite trends of timing in the myodynamic programme shown by items 2 and 3.

Table 5.2.2 Myodynamic, Aerodynamic and Acoustic Measures of Monosyllabic Minimal Pair Words containing Long Versus Short Vowels (Open and Close)

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Mydynamic timing in msec between occlusion offset of the initial plosive and Ac minimum of the final fricative									
/daas/	205	210	215	205	195	185	200	11	(-) 0.31
/das/	185	205	185	170	215	195	190		
/diis/	175	155	180	160	185	185	175	17.5	(-) -
/dis/	180	165	180	185	165	160	175		
2. Duration of vocal folds adduction of vocoids in msec									
/daas/	150	140	130	150	150	115	140	0	** 0.002
/das/	85	90	95	90	95	80	90		
/diis/	125	115	130	100	130	110	120	0	** 0.002
/dis/	65	60	70	70	80	60	65		
3. Mydynamic duration of supraglottal constriction of the final contoid (fricative) in msec									
/daas/	60	60	60	60	45	45	55	0	** 0.002
/das/	80	85	85	95	100	100	90		
/diis/	50	70	55	60	55	70	60	0	** 0.002
/dis/	95	90	100	100	100	100	95		

Table 5.2.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
4. Uo at Ac minimum in L/m of the final contoid (fricative)									
/daas/	8	11	8	5.5	7	11	8.4	16.5	(-) less than 0.938
/das/	4.5	9	5.5	6	11	12	8		
/diis/	5	7	11	6	11	7	7.8	8	(-) 0.132
/dis/	8	8	12	12	10	9	9.8		
5. Po at Ac minimum in cm H_2O of the final contoid (fricative)									
/daas/	14.5	14.5	13	13.5	16	15	14.4	11	(-) 0.31
/das/	16	14.5	15	14.5	15	15	15		
/diis/	15	16.5	15	15	15	16.5	15.5	11	(-) 0.31
/dis/	17	16	14	15.5	17.5	16.5	16		
6. Ac minimum (u/ /$\overline{\Delta P}$) of the final contoid (fricative)									
/daas/	2.109	2.889	2.219	1.497	1.750	2.840	2.226	15.5	(-) less than 0.818
/das/	1.125	2.363	1.420	1.576	2.840	3.098	2.070		
/diis/	1.290	1.515	2.840	1.549	2.840	1.723	1.959	11	(-) 0.31
/dis/	1.455	2.000	3.207	3.048	2.390	2.216	2.386		

Table 5.2.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
7. Acoustic duration of vocoids in msec									
/daas/	185	195	180	175	170	170	180	0	** 0.002
/das/	130	130	125	115	140	130	130		
/diis/	155	155	165	135	170	160	155	0	** 0.002
/dis/	110	100	110	110	110	100	105		
8. Acoustic duration of the final contoid in msec									
/daas/	95	80	70	95	105	105	90	0	** 0.002
/das/	130	155	130	145	140	130	140		
/diis/	65	70	45	90	110	110	80	0	** 0.002
/dis/	150	140	140	135	170	150	145		
9. Word overall acoustic timing in msec. T1 (1)									
/daas/	360	325	295	340	340	260	320	18	(-) -
/das/	310	350	300	305	340	335	325		
/diis/	295	280	275	305	340	335	305	11.5	(-) less than 0.394
/dis/	310	310	305	300	350	320	315		

(1) Measurements were made on the duplex oscillogram from acoustic closure onset of initial plosive to frication noise offset of final fricative

Table 5.2.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
T2 (1)									
/daas/	285	265	245	270	265	235	260	14.5	(-) less than 0.7
/das/	245	270	250	245	265	250	255		
/diis/	235	220	220	235	270	265	240	13.5	(-) less than 0.588
/dis/	240	230	250	235	270	240	245		

(1) Measurements were made on the duplex oscillogram from acoustic closure onset of initial plosive to frication noise onset of final fricative

Two points are worth observing here; firstly the overall timing of the myodynamic programme is consistent with the overall timing of the acoustic output. Secondly, the temporal compensation between the durations of the preceding vocoid and the following contoid can be seen on both the myodynamic and the acoustic levels. For further discussion of these findings see Chapter Six, Section 6.1.3.

5.4.2 Voicing and Manner of Articulation of the Following Contoid

5.4.2.1 Voiced Versus Voiceless Fricatives

Table 5.3.1 shows results for words in minimal pairs containing final voiced versus voiceless fricatives. It consists of eight items comprising myodynamic, aerodynamic and acoustic measures. Each item contains two minimal pairs; when voiced versus voiceless fricatives are preceded by (a) long vowels as in /baaz/ versus /baas/, (b) short vowels as in /baz/ versus /bas/.

This table shows the following results:

1. Item 1 shows no significant differences in myodynamic timings for both minimal pairs suggesting that the timing of executing Ac minimum, the cross-sectional area of constriction, is the same for [z] and [s].

2. Items 2 and 3 show very significant differences in the aerodynamic conditions i.e. volume of airflow rate and intraoral pressure, associated with the production of the final fricatives [z] and [s] as shown in Figures 5.12 and 5.13.

3. Item 4 shows that the durations of vocal folds adductions of vocoids are not different when preceding voiced versus voiceless fricatives for both minimal pairs.

4. The myodynamic durations of the segments [z] and [s] are also shown by item 5 to have no significant differences for both minimal pairs.

5. Item 6 shows a very significant difference in Ac minimum between [z] and [s] i.e. the minimum cross-sectional area of constriction is very significantly larger for [s] than for [z] for both minimal pairs.

6. Item 7 shows thatthe acoustic duration of vocoid is very significantly longer when preceding [z] than when preceding [s] showing the same trend as found in Chapter Four (see Section 4.3.2).

7. Item 8 shows an opposite trend to that of item 7; the acoustic duration of [z] is very significantly shorter than [s].

It is interesting to observe two important facts

Table 5.3.1 Myodynamic, Aerodynamic and Acoustic Measures of Mono-syllabic Minimal Pair words containing Voiced Versus Voiceless Fricatives

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Myodynamic timing in msec between occlusion offset of the initial plosive and Ac minimum of the final fricative									
/baaz/	200	185	175	180	165	155	175	15.5	(-) less than 0.818
/baas/	180	165	185	185	150	165	170		
/baz/	160	160	180	170	155	130	160	16.5	(-) less than 0.938
/bas/	170	140	165	180	140	130	155		
2. Uo at Ac minimum in L/m of final fricative									
/baaz/	5	4	3	3	6	5	4.3	0.5	** less than 0.004
/baas/	14	8	10	6	12	18	11.3		
/baz/	4	4	4	5	5	3	4.2	0	** 0.002
/bas/	10	8	8	8	6	12	8.7		
3. Po at Ac minimum in cm H_2O of the final fricative									
/baaz/	5	6	7.5	7.5	5	4	5.8	0	** 0.002
/baas/	10.5	10.5	8.5	10	11	8	9.7		
/baz/	7	6	8.5	5	7	7.5	6.8	0	** 0.002
/bas/	11	11	11	10	11	12	11		

Table 5.3.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
4. Duration of V.Fs adduction of vocoid in msec									
/baaz/	115	95	85	80	80	85	90	13	(-) 0.484
/baas/	85	80	85	85	75	85	85		
/baz/	60	50	60	45	45	45	50	9.5	less than 0.240
/bas/	55	40	55	40	40	45	45		
5. Myodynamic duration of supraglottal constriction in msec of the final fricative									
/baaz/	80	55	55	55	60	40	55	9	0.180
/baas/	45	50	55	45	45	55	50		
/baz/	85	80	85	85	85	85	85	10.5	(-) less than 0.31
/bas/	80	80	85	95	70	45	75		
6. AC minimum u/ /$\overline{\Delta P}$ of the final fricative									
/baaz/	2.236	1.633	1.095	1.095	2.683	2.500	1.874	6	* 0.064
/baas/	4.321	2.160	3.430	1.897	3.618	6.365	3.631		
/baz/	1.512	1.633	1.372	2.236	1.890	1.095	1.623	2	** 0.008
/bas/	3.015	2.412	2.412	2.530	1.809	3.464	2.607		

Table 5.3.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
7. Acoustic duration of vocoid in msec									
/baaz/	170	165	160	155	130	130	150	4	0.026**
/baas/	130	125	140	130	110	125	125		
/baz/	105	115	115	110	100	85	105	4	0.026**
/bas/	85	95	100	90	75	70	85		
8. Acoustic duration of the final fricative in msec									
/baaz/	40	55	40	40	60	55	50	0	0.002**
/baas/	100	110	105	70	95	95	95		
/baz/	110	80	85	55	80	80	80	0	0.002**
/bas/	140	130	125	140	115	130	130		

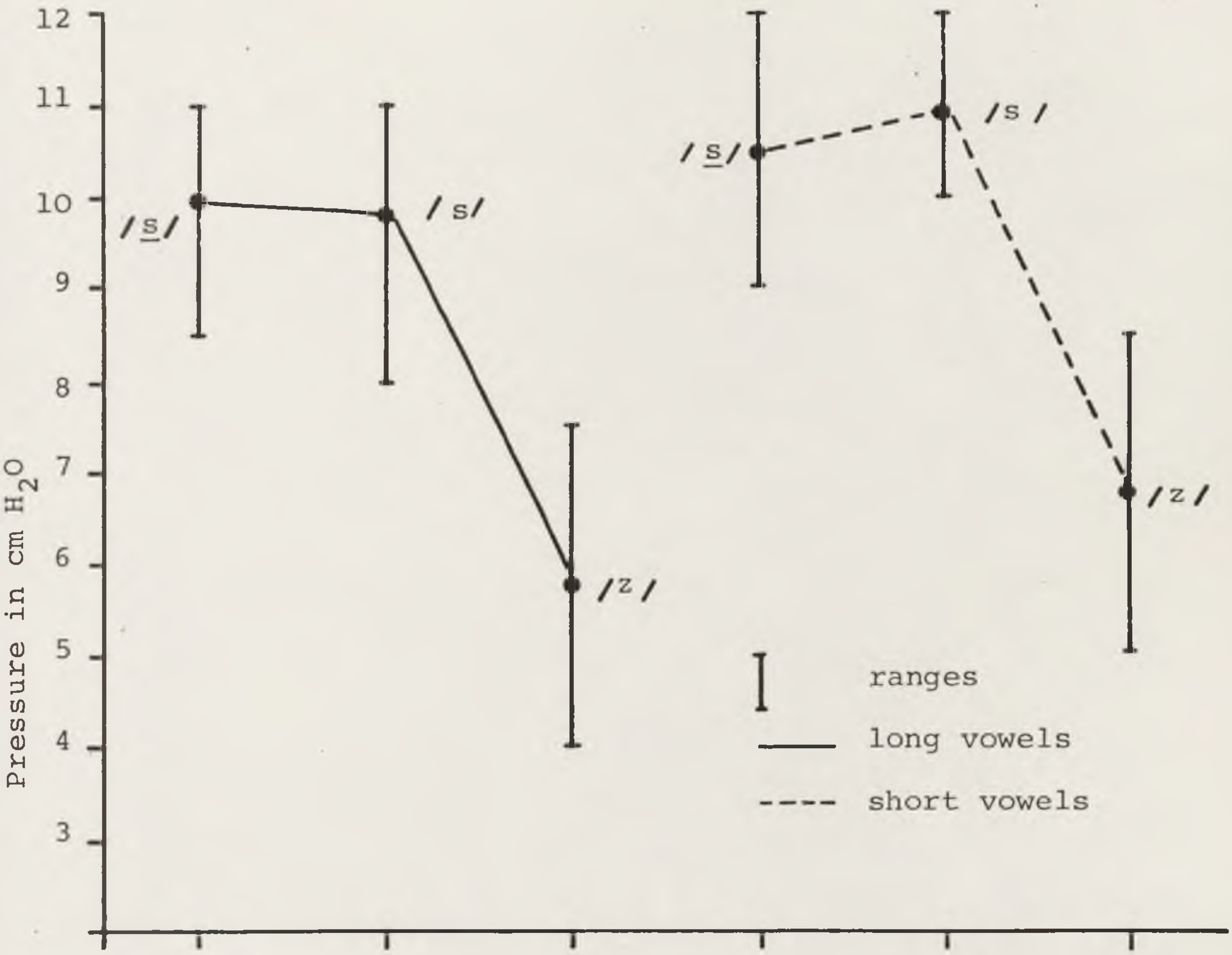


Fig. 5.12

Average values of intraoral pressure in cm H_2O at Ac min. of the fricatives /s̲/, /s/ and /z/ following long and short vowels. Words compared are /baas̲/, /baas/ and /baaz/ (long vowels) and /bas̲/, /bas/ and /baz/ (short vowels).

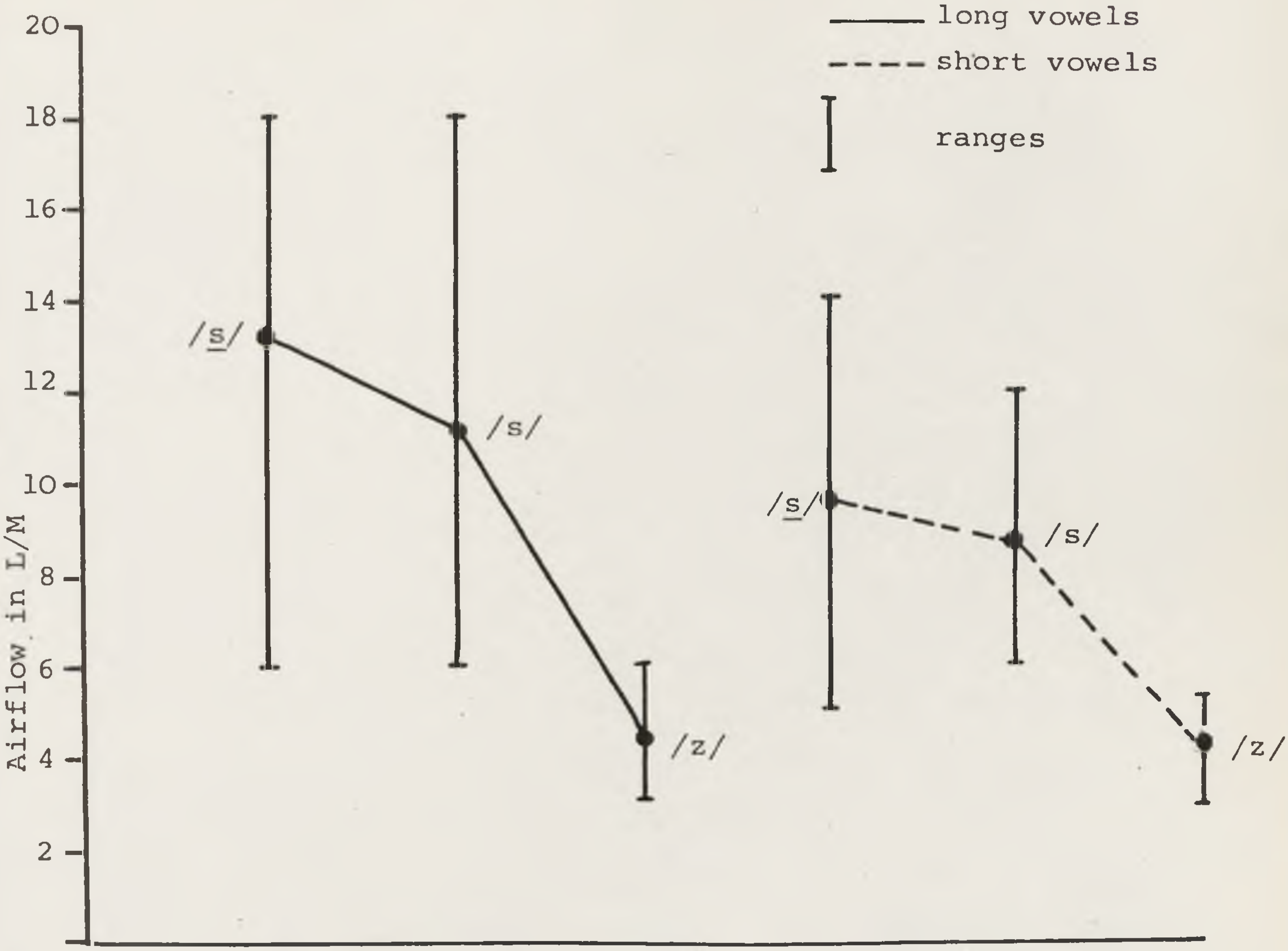


Figure 5.13. Airflow in L/M at Ac min. for the fricatives /s/, /s/ and /z/ following long and short vowels. Words compared are /baas/, /baas/ and /baaz/ (long vowels) and /bas/, /bas/ and /baz/ (short vowels).

revealed by this table; firstly, differences in acoustic durations cannot be ascribed to differences in myodynamic durations i.e. the differences in the acoustic durations of the preceding vocoids as well as the following contoids do not have corresponding differences, on the myodynamic level, in the duration of the vocal folds adduction of the preceding vocoid and the myodynamic duration of the following contoid respectively, nor is there any difference in the myodynamic timings of the words in question. Secondly, the only significant differences are those shown by the aerodynamic conditions, airflow and intraoral pressure, as well as Ac minimum as suggested by items 2, 3 and 6. Consequently, one can feasibly ascribe the differences in acoustic durations to differences in the aerodynamic conditions which are the only significantly different variables besides the Ac minimum shown in this table.

5.4.2.2 Voiced Versus Voiceless Plosives

Table 5.3.2 shows results for monosyllabic minimal pairs of words containing final voiced versus voiceless plosives. It consists of six items comprising myodynamic, aerodynamic and acoustic measures. Each item contains two minimal pairs; when voiced versus voiceless plosives are preceded by (a) long vowels as in /baad/ versus /baat/, (b) short vowels as in /bad/ versus /bat/.

This table shows the following:

1. Item 1 shows no significant differences in myodynamic timing for both minimal pairs. Neither T1 nor T2 shows any significant differences.

2. Item 2 also shows non-significant differences in the duration of vocal folds adduction of vocoids preceding voiced versus voiceless plosives for both minimal pairs.

3. Item 3 shows no significant differences in the myodynamic duration of the final plosive.

4. Intraoral pressure is shown by item 4 to be very significantly higher for [t] than for [d] for both minimal pairs as shown in Figure 5.14.

5. The acoustic duration of vocoid is shown by item 5 to be very significantly longer when preceding [d] than when preceding [t] showing the same trend as that found in Chapter Four (see Section 4.3.2).

6. The acoustic duration of the final contoid i.e. the duration of the acoustic closure of the final plosive is shown by item 6 to be significantly longer for [t] than for [d] in /baat/ versus /baad/ (long vowels) and very significantly longer in /bat/ versus /bad/ (short vowels).

The results of this table match up those of Table 5.3.1 (see previous section) in that the differences in

Table 5.3.2 Myodynamic, Aerodynamic and Acoustic Measures of Monosyllabic Minimal Pair Words containing Voiced Versus Voiceless Plosives

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Myodynamic timing in msec									
(a) T1 - between occlusion offset of the initial plosive and the occlusion onset of the final plosive									
/baad/	140	145	155	165	130	145	145	16.5	(-) 0.938
/baat/	145	150	150	150	130	150	145		
/bad/	90	95	110	80	100	80	90	12.5	(-) less than 0.484
/bat/	90	80	90	75	100	85	85		
(b) T2 - between occlusion offset of the initial plosive and the occlusion offset of the final plosive									
/baad/	180	190	205	200	180	195	190	10	(-) 0.240
/baat/	205	205	210	200	175	200	200		
/bad/	190	195	210	185	210	180	190	14	(-) 0.588
/bat/	215	210	205	185	200	185	200		
2. Duration of V.Fs adduction of vocoid in msec									
/baad/	95	100	95	105	80	100	95	12	(-) 0.394
/baat/	95	100	85	80	80	100	90		
/bad/	55	50	60	35	80	50	55	12	(-) less than 0.394
/bat/	45	50	55	30	60	40	45		

Table 5.3.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
3. Myodynamic duration of the occlusion of the final plosive in msec									
/baad/	40	45	50	35	50	50	45	6.5	(-) less than 0.094
/baat/	60	55	60	50	45	50	55		
/bad/	100	100	100	105	110	100	105	8.5	(-) less than 0.180
/bat/	125	130	115	110	100	100	115		
4. Peak Po in cm H_2O of the final plosive									
/baad/	7	6	8	6.5	8	7	7.1	0	** 0.002
/baat/	12.5	13	17	13.5	16.5	14	14.4		
/bad/	6	4	6.5	5.5	6	7	5.8	0	** 0.002
/bat/	12.5	11	11.5	12	12.5	12.5	12		
5. Acoustic duration of vocoid in msec									
/baad/	150	150	165	165	150	155	155	4.5	† ** less than 0.042
/baat/	145	150	150	145	125	150	145		
/bad/	95	95	110	85	100	85	95	4	† ** 0.026
/bat/	95	70	80	70	85	80	80		

Table 5.3.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
6. Acoustic duration of the final contoid in msec									
/baad/	45	55	50	40	45	45	45	5.5	T * less than 0.064
/baat/	60	60	55	50	45	60	55		
/bad/	80	95	80	85	80	80	85	1.5	** less than 0.008
/bat	115	125	115	110	85	100	110		

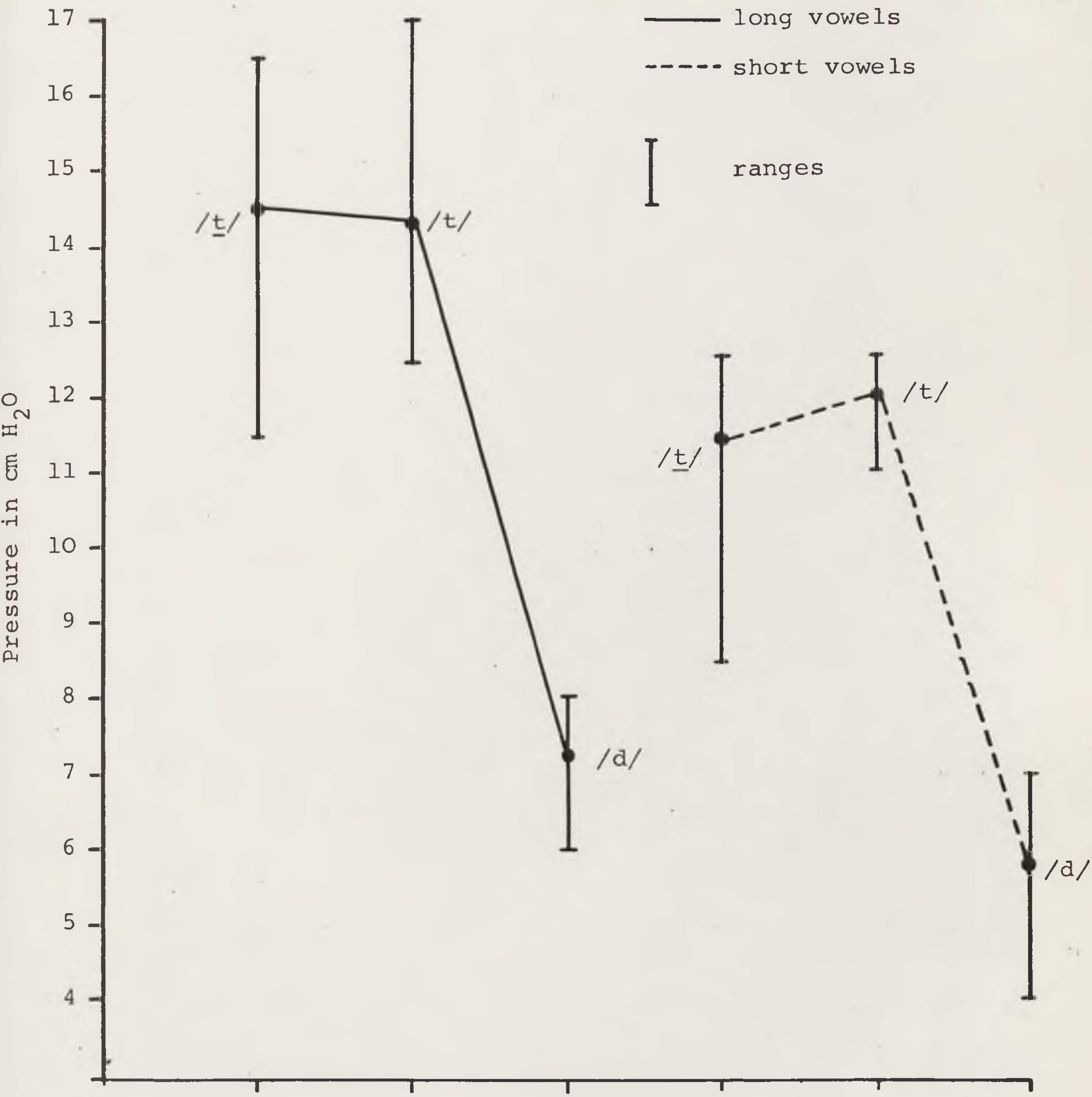


Figure 5.14. Average values of intraoral pressure of the plosives /t̲/, /t/ and /d/ following open long and short vowels. Words compared are /baat̲/, /baat/ and /baad/ (long vowels) and /bat̲/, /bat/ and /bad/ (short vowels).

the acoustic durations of vocoids and following contoids do not have corresponding differences, on the myodynamic level, in the duration of vocal folds adduction of vocoids and the myodynamic duration of the occlusion of the final plosive. Hence, these differences may be well attributed to the differences in intraoral pressure which showed very significantly higher values for [t] than for [d] for both minimal pairs. The results of both tables will be discussed further in Chapter Six. See Section 6.2.3

5.4.2.3 Voiceless Emphatic Versus Non-emphatic Fricatives

Table 5.3.3 deals with the investigation of minimal pairs of words containing voiceless emphatic versus non-emphatic fricatives. It consists of eight items comprising myodynamic, aerodynamic and acoustic measures. Each item contains two minimal pairs; when the fricatives in question are preceded by (a) long vowels as in /baas̠/ versus /baas/, (b) short vowels as in /bas̠/ versus /bas/.

This tables shows the following results:

1. Item 1 shows that the myodynamic timing is very significantly longer when the vocoid precedes an emphatic fricative than when it precedes a non-emphatic one for both long and short vowels suggesting that the execution of Ac minimum is delayed more for [s̠] than for [s].

2. The aerodynamic events associated with [s̠] and [s]

are shown by item 2 and 3 to have no significant differences. Neither Uo nor Po shows any significant differences for both minimal pairs. (See Figures 5.12 and 5.13).

3. Item 4 shows compatible trend with that of item 1; the duration of vocal folds adduction is very significantly longer for vocoids preceding [s̠] than those preceding [s] for both minimal pairs, suggesting that the delay in executing Ac minimum is accompanied by a similar delay in abducting the vocal folds for the following contoid.

4. The myodynamic duration of the final fricative has been shown by item 5 to have no significant differences for [s̠] and [s] in both minimal pairs; nor is there any significant difference in Ac minimum for both fricatives as suggested by item 6.

5. Item 7 shows very significant differences in the acoustic duration of vocoids for both minimal pairs. Vocoid duration preceding [s̠] is very significantly longer in /baas̠/ versus /baas/ (long vowels) and only significantly longer in /bas̠/ versus /bas/ (short vowels) showing the same trend as that found in Chapter Four (see Section 4.3.2).

6. Item 8 shows no significant differences in the acoustic duration of the final fricative for both minimal pairs showing compatible trend with that of item 5.

Considering the results shown by the above items more

Table 5.3.3 Myodynamic, Aerodynamic and Acoustic Measures of Monosyllabic Minimal Pair Words containing Voiceless Emphatic Versus Non-emphatic Fricatives

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Myodynamic timing in msec between occlusion offset of the initial plosive and Ac minimum of the following fricative									
/baas̲/	220	-	195	205	200	225	210	0	** 0.004
/baas/	180	165	185	185	150	165	170		
/bas̲/	180	165	195	180	180	185	180	4	** 0.026
/bas/	170	140	165	180	140	130	155		
2. Uo at Ac minimum in L/m of the final fricative									
/baas̲/	18	-	6	8	18	16	13.2	12	(-) 0.662
/baas/	14	8	10	6	12	18	11.3		
/bas̲/	8	5	12	8	12	14	9.8	14	(-) 0.588
/bas/	10	8	8	8	6	12	8.7		
3. Po at Ac minimum in cm H_2O of the final frication									
/baas̲/	10	-	10.5	11	10	8.5	10	14	(-) 0.588
/baas/	10.5	10.5	8.5	10	11	8	9.7		
/bas̲/	11	12	9	11	11	-	10.5	14.5	(-) less than 0.7
/bas/	11	11	11	10	11	12	11		

Table 5.3.3 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
4. Duration of V.Fs adduction of vocoids in msec									
/baas̲/	125	80	110	90	95	110	100	4.5	** less than 0.042
/baas/	85	80	85	85	75	85	85		
/bas̲/	70	55	70	55	55	70	65	3	** 0.016
/bas/	55	40	55	40	40	45	50		
5. Myodynamic duration of supraglottal constriction of the final fricative in msec									
/baas̲/	40	-	45	55	60	40	50	17.5	(-) -
/baas/	45	50	55	45	45	55	50		
/bas̲/	80	60	70	80	60	80	70	12.5	(-) less than 0.484
/bas/	80	80	85	95	70	45	75		
6. AC minimum $u/\sqrt{\Delta P}$ of the final fricative									
/baas̲/	5.692	-	1.852	2.412	5.692	5.489	4.227	14	(-) 0.465
/baas/	4.321	2.469	3.430	1.897	3.618	6.365	3.630		
/bas̲/	2.419	1.443	4.000	2.419	3.618	-	2.780	18	(-) -
/bas/	3.015	2.412	2.412	2.530	1.809	3.464	2.607		

Table 5.3.3 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
7. Acoustic duration of vocoids in msec									
/baas/	165	130	150	140	130	175	150	4.5	** less than 0.042
/baas/	130	125	140	130	110	125	125		
/bas/	100	95	100	100	95	95	95	6	* 0.064
/bas/	85	95	100	90	75	70	85		
8. Acoustic duration of the final fricative(1)									
/baas/	100	125	95	95	85	85	95	15.5	(-) less than 0.818
/baas/	100	110	105	70	95	95	95		
/bas/	145	130	150	135	130	130	135	11	(-) 0.31
/bas/	140	130	125	140	115	130	130		

closely one may observe the following points:

Since the results showed no significant differences in Uo, Po, Ac minimum, as well as the myodynamic duration of the supraglottal constriction and the corresponding acoustic duration of the final fricative, it is likely that the delay of executing the constriction of the following emphatic fricative [s̲] would in its turn necessitate prolonging the adduction of vocal folds and hence prolonging the acoustic duration of the preceding vocoid. This will be discussed in more detail in Chapter Six (see Section 6.3.3).

5.4.2.4 Voiceless Emphatic Versus Non-emphatic Plosives

Table 5.3.4 deals with the investigation of minimal pairs of words containing final voicelss emphatic versus non-emphatic plosives. It comprises myodynamic, aerodynamic and acoustic measures. Each item contains two minimal pairs: when these plosives are preceded by (a) long vowels as in /baat̲/ versus /baat/, (b) short vowels as in /bat̲/ versus /bat/.

This table shows the following results:

1. Item 1a shows very significant difference† in T1 for /baat̲/ versus /baat/ and significant differences† for /bat̲/ versus /bat/ suggesting that the occlusion onset of [t̲] is delayed more than that for [t] in both minimal pairs. On the other hand, T2 is shown by b of the same

item to have no significant differences for the respective minimal pairs.

2. Item 2 shows that the durations of vocal folds adduction of vocoids are significantly longer when preceding [ṯ] than when preceding [t] for both minimal pairs showing compatible trend to that of item 1a as well as that found in Table 5.3.3 viz: the longer the myodynamic timing for words with final emphatic, the longer the duration of vocal folds adduction of the preceding vocoids and vice versa for non-emphatic plosives.

3. Item 3 shows that the myodynamic duration of the supraglottal constriction is very significantly longer for [t] than for [ṯ] in /baaṯ/ versus /baat/ but not significantly different for /baṯ/ versus /bat/.

4. Po of the final plosive is shown by item 4 to have no significant differences for both minimal pairs. (See Figure 5.14).

5. The acoustic duration of vocoid is shown by item 5 to be significantly longer for /baaṯ/ than for /baat/ and significantly longer for /baṯ/ than for /bat/ showing the same trend as that found in Chapter Four (see Section 4.3.2).

6. The acoustic duration of the final contoid i.e. the duration of the acoustic closure is shown by item 6 to have no significant difference.

Table 5.3.4 Myodynamic, Aerodynamic and Acoustic Measures of Monosyllabic Minimal Pair Words containing Voiceless Emphatic Versus Non-emphatic Plosives

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Myodynamic timing in msec									
(a) T1 - between occlusion offset of the initial plosive and the occlusion onset of the final plosive									
/baat̲/	165	155	150	155	160	150	155	4 †	** 0.026
/baat/	145	150	150	150	130	150	145		
/bat̲/	95	95	110	95	95	90	95	6 †	* 0.064
/bat/	90	80	90	75	100	80	85		
(b) T2 - between occlusion offset of the initial plosive and the occlusion offset of the final plosive									
/baat̲/	220	195	180	195	185	195	195	11	(-) 0.31
/baat/	205	205	210	200	175	200	200		
/bat̲/	205	220	245	220	190	200	215	10	(-) 0.240
/bat/	215	210	205	185	200	185	200		
2. Duration of V.Fs adduction of vocoids in msec									
/baat̲/	125	105	100	95	100	100	105	5.5 †	* less than 0.064
/baat/	95	100	85	80	80	100	90		
/bat̲/	55	55	55	55	65	70	57.5	6 †	* 0.064
/bat/	45	50	55	30	60	40	45		

Table 5.3.4 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
6. Acoustic duration of final contoid in msec									
/baaṯ/	65	55	55	50	35	35	50	12.5	(-) less than 0.424
/baat/	60	60	55	50	45	60	55		
/baṯ/	115	110	115	115	95	95	110	16.5	(-) less than 0.938
/bat/	115	125	115	110	85	100	110		

It seems from the results above that the articulatory timing associated with producing these words is very similar to those of /baas̱/ versus /baas/ and /bas̱/ versus /bas/ as shown in Table 5.3.3 indicating the same trend viz: the delay of executing the constriction of the final [t̠] is also accompanied by a corresponding delay in abducting the vocal folds and hence prolonging the acoustic duration of the preceding vocoids.† See Section 6.3.3 for further discussion of this problem.

5.4.3 Place of Articulation of the Following Contoid

Tables 5.4.1 and 5.4.2 deal with the investigation of the articulatory timing associated with the different places of articulation of the final contoid. The test words were arranged to form a front-to-back pattern of the following contoid.

Table 5.4.1 comprises measurements of myodynamic timings and acoustic duration of vocoids when the final contoid is voiceless fricative. The table consists of four major categories having a number of items. Each item is divided into (a) myodynamic timing between Ac minimum of the initial fricative and Ac minimum of the following fricative in msec established at the dip of the airflow trace (see Section 5.3.2), (b) acoustic duration of vocoids in msec.

Category (A) deals with a comparison of labio-dental with denti-alveolar, palato-alveolar, uvular and pharyngeal fricatives. It consists of four items showing the following results:

1. Items 1, 2 and 3 show no significant differences for both (a) and (b) i.e. neither the myodynamic timing nor the acoustic duration of vocoids shows any significant differences for /faaf/ versus /faas/, /faaf/ versus /faaʃ/ and /faaf/ versus /faax/.

2. Item 4 shows very significant differences for both (a) and (b); the myodynamic timing between Ac. minimum of the initial fricative and Ac. min. of the final fricative is shown to be very significantly longer for /faaf/ than for /faaħ/ suggesting that the constriction for [ħ] is executed earlier than that for [f]. The acoustic duration of vocoids is also shown to be very significantly longer for /faaf/ than for /faaħ/.

Category (B) deals with a comparison of denti-alveolar with palato-alveolar, uvular and pharyngeal fricatives. It consists of three items showing the following results:

1. Neither the myodynamic nor the acoustic duration of vocoids is shown by item 1 to have any significant differences for /faas/ versus /faaʃ/.

2. Item 2 shows very significant differences for both (a) and (b) suggesting that the constriction for [x] is executed earlier than that for [s] and a longer acoustic duration for /faas/ than for /faax/.

3. Item 3 for both (a) and (b) shows very significant differences suggesting that the constriction of the pharyngeal fricative [ħ] is executed earlier and perhaps with more efficiency than that for [s], considering the relatively higher level of significance at $p = 0.002$ as well as the larger difference in average value being 50 msec. The acoustic duration of vocoids also shows relatively higher values of p as well as in average difference being at $p = 0.04$ and 35 msec respectively.

Category (C) deals with a comparison of palato-alveolar with uvular and pharyngeal fricatives showing the following results:

1. Both (a) and (b) are shown by item 1 to have no significant differences for /faaʃ/ versus /faax/.

2. Item 2 shows very significant differences for both (a) and (b); the myodynamic timing as well as the acoustic duration of vocoids are very significantly longer for /faaʃ/ than for /faaħ/.

Category (D) consists of only one item dealing with the comparison of uvular with pharyngeal fricatives. It shows for (a) a very significant difference but only significant difference for (b); the myodynamic timing and the acoustic duration of vocoid are very significantly and significantly longer for /faax/ than for /faaħ/ respectively.

Table 5.4.1 Myodynamic Timings[(1)] and Acoustic Durations of Vocoids of Monosyllabic Minimal Pair Words having Different Places of Articulation of the Following Contoid (Voiceless Fricatives)

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
A.									
1. Labio-dental versus denti-alveolar									
(a) Myodynamic timing in msec									
/faaf/	245	205	215	215	230	210	220	9	(-) 0.180
/faas/	220	225	220	220	235	265	230		
(b) Acoustic duration of vocoid in msec									
/faaf/	140	115	120	110	125	110	120	6.5	(-) less than 0.094
/faas/	130	140	155	120	120	155	135		
2. Labio-dental versus palato-alveolar									
(a) Myodynamic timing in msec									
/faaf/	245	205	215	215	230	210	220	18	(-) -
/faaʃ/	235	235	235	200	215	195	220		
(b) Acoustic duration of vocoid in msec									
/faaf/	140	115	120	110	125	110	120	15	(-) 0.7
/faaʃ/	140	125	140	125	105	110	125		

(1) Airflow minimum was used as equivalent to Ac minimum for all the word final fricatives used in the comparisons of this table as well as table 5.4.2. For details see Section 5.3.2.

Table 5.4.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	P
3. Labio-dental versus uvular									
(a) Myodynamic timing in msec									
/faaf/	245	205	215	215	230	210	220	14	(-) 0.588
/faax/	215	215	200	220	225	195	210		
(b) Acoustic duration of vocoid in msec									
/faaf/	140	115	120	110	125	110	120	16	(-) 0.818
/faax/	120	125	125	100	105	120	115		
4. Labio-dental versus pharyngeal									
(a) Myodynamic timing in msec									
/faaf/	245	205	215	215	230	210	220	0	** 0.002
/faaħ/	165	180	185	185	165	195	180		
(b) Acoustic duration of vocoid in msec									
/faaf/	140	115	120	110	125	110	120	4.5	** less than 0.042
/faaħ/	100	120	110	85	95	100	100		
B.									
1. Denti-alveolar versus palato-alveolar									
(a) Myodynamic timing in msec									
/faas/	220	225	220	220	235	265	230	13.5	(-) less than 0.588
/faaʃ/	235	235	235	200	215	195	220		

Table 5.4.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
(b) Acoustic duration of vocoid in msec									
/faas/	130	140	155	120	120	155	135	11	(-) 0.31
/faaʃ/	140	125	140	125	105	110	125		
2. Denti-alveolar versus uvular									
(a) Myodynamic timing in msec									
/faas/	220	225	220	220	235	265	230	5 †	** 0.042
/faax/	215	215	200	220	225	195	210		
(b) Acoustic duration of vocoid in msec									
/faas/	130	140	155	120	120	155	135	6 †	* 0.064
/faax/	120	125	125	100	105	120	115		
3. Denti-alveolar versus pharyngeal									
(a) Myodynamic timing in msec									
/faas/	220	225	220	220	235	265	230	0	** 0.002
/faaħ/	165	180	185	185	165	195	180		
(b) Acoustic duration of vocoid in msec									
/faas/	130	140	155	120	120	155	135	1	** 0.004
/faaħ/	100	120	110	85	95	100	100		

Table 5.4.1 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
C.									
1. Palato-alveolar versus uvular									
(a) Myodynamic timing in msec									
/faaʃ/	235	235	235	200	215	195	220	13	0.484
/faax/	215	215	200	220	225	195	210		
(b) Acoustic duration of vocoid in msec									
/faaʃ/	140	125	140	125	105	110	120	10.5	(-) less than 0.31
/faax/	120	125	125	100	105	120	115		
2. Palato-alveolar versus pharyngeal									
(a) Myodynamic timing in msec									
/faaʃ/	235	235	235	200	215	195	220	0.5	** less than 0.004
/faaħ/	165	180	185	185	165	195	180		
(b) Acoustic duration of vocoid in msec									
/faaʃ/	140	125	140	125	105	110	125	3.5	** less than 0.026
/faaħ/	100	120	110	85	95	100	100		

Table 5.4.1 continued

Utterances	Tokens						Av	U	p
	1	2	3	4	5	6			
D.									
Uvular versus pharyngeal									
(a) Myodynamic timing in msec									
/faax/	215	215	200	220	225	195	210	0.5	** less than 0.004
/faaħ/	165	180	185	185	165	195	180		
(b) Acoustic duration of vocoid in msec									
/faax/	120	125	125	100	105	120	115	6 †	* 0.064
/faaħ/	100	120	110	85	95	100	100		

Table 5.4.2 also comprises measurements of myodynamic timing and acoustic duration of vocoids, with the same criteria of measurement but when the final vocoid is voiced fricative. It comprises two categories:

Category (A) deals with comparing denti-alveolar with uvular and pharyngeal voiced fricatives. It consists of two items showing the following results:

1. Neither the myodynamic timing nor the acoustic duration of vocoids is shown by item 1 to have any significant differences for /baaz/ versus /baaɣ/.

2. The myodynamic timing as well as the acoustic duration of vocoids are shown by item 2 to have very significant differences for /baaz/ versus /baaʕ/.

Category (B) consists of one item showing very significant differences for (a) and (b); the myodynamic timing is very significantly longer for /baaɣ/ than for /baaʕ/ and the acoustic duration of vocoids is significantly longer for /baaɣ/ than for /baaʕ/.

From the results shown by Tables 5.4.1 and 5.4.2, two trends strongly suggest themselves:

(i) The longer the myodynamic timing of the test monosyllabic word, the longer the acoustic duration of vocoids and vice versa as shown in Figure 5.15 i.e. the delay of executing the constriction of the final

Table 5.4.2 Myodynamic Timing and Acoustic Duration of Vocoids in msec of Monosyllabic Minimal Pair Words having Difference Places of Articulation of the following Consonants (Voiced Fricatives)

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
A.									
1. Denti-alveolar versus uvular									
(a) Myodynamic timing in msec									
/baaz/	200	185	175	180	165	155	175	11.5	(-) less than 0.662
/baaɣ/	-	190	185	185	170	175	180		
(b) Acoustic duration of vocoids in msec (1)									
/baaz/	170	165	160	155	135	135	155	15	(-) 0.7
/baaɣ/	165	155	155	135	130	165	150		
2. Denti-alveolar versus pharyngeal									
(a) Myodynamic timing in msec									
/baaz/	200	185	175	180	165	155	175	4.5	** less than 0.042
/baaʕ/	165	165	150	135	165	140	155		
(b) Acoustic duration of vocoid in msec									
/baaz/	170	165	160	155	135	135	155	5	** 0.042
/baaʕ/	150	140	135	110	130	120	130		

(1) All acoustic durations of both tables 5.4.1 and 5.4.2 have shown the same trend as that shown by our acoustic data in Chapter Four except for /baaz/ versus /baaɣ/. Acoustic vocoid duration of /baaz/ has been shown in Chapter Four to be very significantly longer than that of /baaɣ/.

Table 5.4.2 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
B.									
Uvular versus pharyngeal									
(a) Myodynamic timing in msec									
/baaɣ/	-	190	185	185	170	175	180	0	0.004**
/baaʕ/	165	165	150	135	165	140	150		
(b) Acoustic duration of vocoid in msec									
/baaɣ/	165	155	155	135	130	165	150	6	0.064**
/baaʕ/	150	140	135	110	130	120	130		

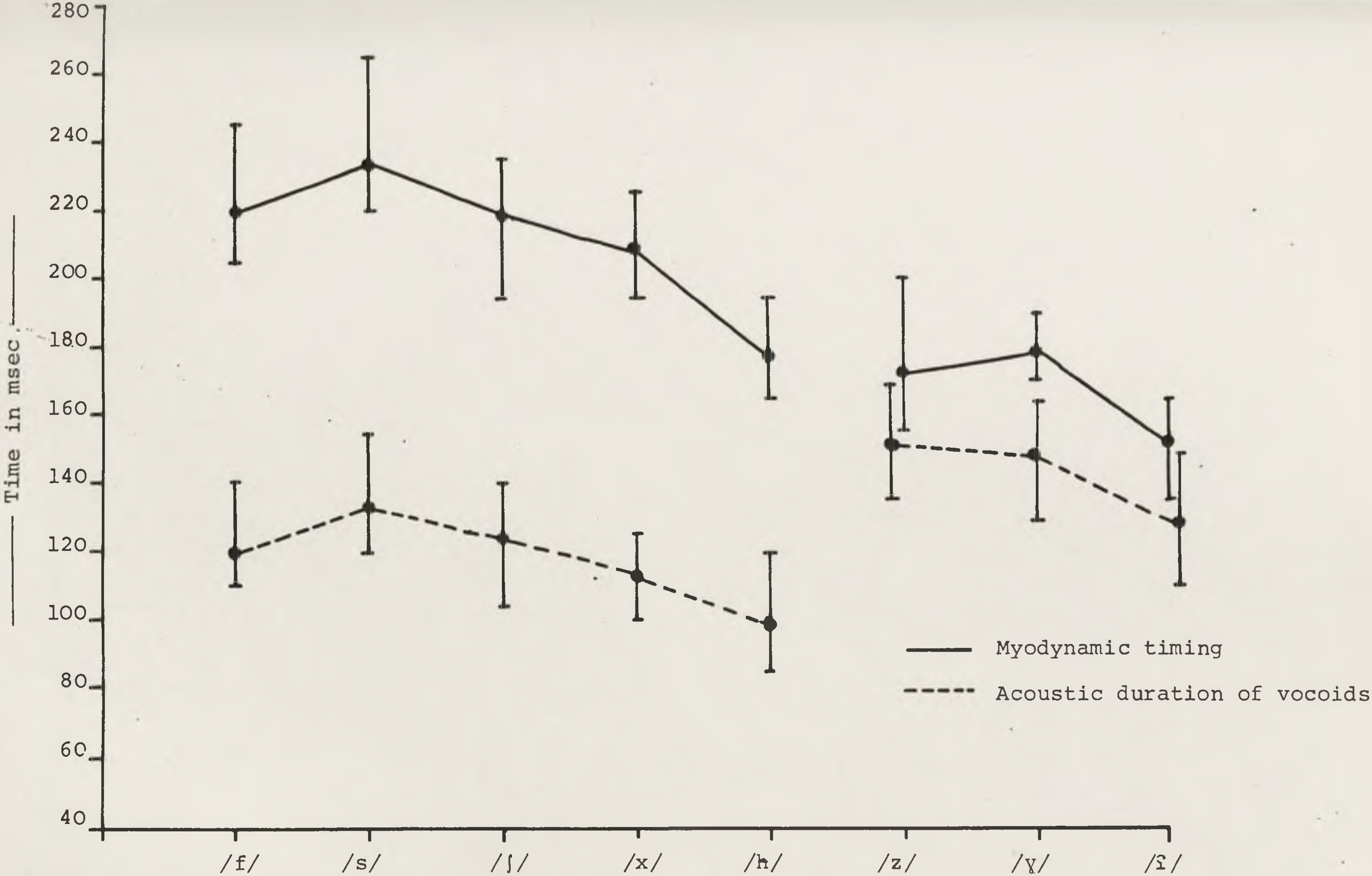


Figure 5.15. Average values of myodynamic timing and acoustic duration of vocoids in msec of words containing different places of articulation of the following consonants. Words compared are /faaf/, /faas/, /faaʃ/, /faax/ and /faaħ/ /voiceless fricatives and /baaz/, /baaɣ/ and /baaʕ/ /voiced fricatives).

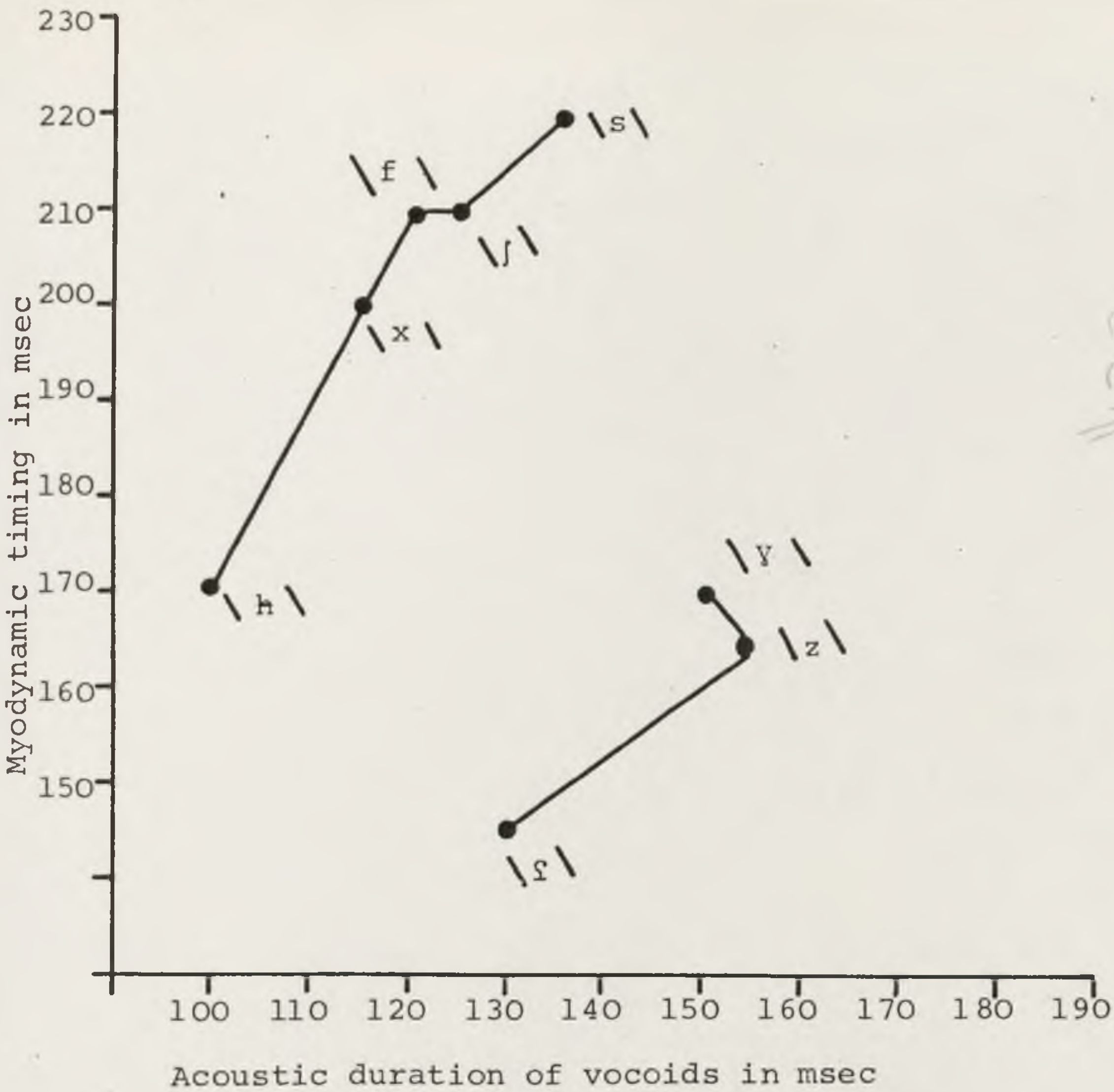


Figure 5.16. Average values of myodynamic timing in msec plotted against average values of acoustic duration of vocoids in msec of words containing different places of articulation of the following contoid. Words compared are: /faaf/, /faas/, /faaʃ/, /faax/ and /faaħ/ (voiceless fricatives) and /baaz/, /baaɣ/ and /baaʕ/ (voiced fricatives).

contoid is always accompanied by a longer duration of the preceding vocoid suggesting that the longer vocoid duration is probably due to a delayed constriction timing of the following contoid.

(ii) The myodynamic timing of the word with final voiceless and voiced fricatives /ħ/ and /ʕ/, and, consequently the acoustic duration of the preceding vocoids are always significantly or very significantly shorter than those of the other test words, see Figure 5.16.

These will be discussed in more detail in Chapter Six (see Section 6.4.3).

5.4.4 Stressed Versus Unstressed Syllables

Table 5.5 deals with the investigation of the myodynamic and aerodynamic correlates of stressed versus unstressed syllables. It consists of seven items comprising myodynamic, aerodynamic and acoustic measures of the first syllable of each of the two bisyllabic similar words /'kitab/ versus /ki'taab/.

This table shows the following results:

1. Item 1(a) shows very significant differences† in T1 suggesting that the execution of the onset of [t] occlusion is more delayed for stressed than for unstressed syllables. On the other hand, T2 shows a non-significant difference.

2. The duration of vocal folds adduction of vocoids is

shown by item 2 to be very significantly longer† for stressed than for unstressed syllables. This is consistent with Tl in the sense that the longer Tl, the longer the duration of vocal folds adduction.

3. Item 3 shows that the duration of occlusion of the final plosive [t] is very significantly longer for unstressed syllables than for stressed syllables.

4. Po of the initial plosive is shown by item 4 to be very significantly higher† for stressed than for unstressed syllables. On the other hand, item 5 shows that Po of the final plosive is very significantly higher when the second syllable is stressed.

5. Item 6 shows that the acoustic duration of vocoids is very significantly longer† for stressed than for unstressed syllable showing the same trend as found in Chapter Four (see Section 4.3.4).

6. The acoustic duration of the intervocalic plosive i.e. the duration of acoustic closure of [t] is shown by item 7 to be very significantly longer† for unstressed syllables than for stressed syllables showing a consistent trend with the corrresponding myodynamic duration of the same plosive as shown by item 3.

It seems evident from the results shown by this table that the stressed syllable i.e. the first syllable of /ˈkitab/ is characterized by the following myodynamic and aerodynamic correlates:

1. † Longer T1 and hence delayed closure time for the final plosive.

2. † Corresponding longer duration of vocal folds adduction of vocoids.

3. † Higher intraoral pressure for the initial plosive [k].

4. † Lower intraoral pressure for the final plosive [t].

5. Shorter myodynamic duration of occlusion of final plosive [t] and corresponding shorter acoustic duration of the same plosive.

On the other hand, the unstressed syllable, i.e. the first syllable of /ki'taab/ is characterized by the following myodynamic and aerodynamic correlates:

1. † Shorter T1 and hence earlier closure time for final plosive [t].

2. † Corresponding shorter vocal folds adduction of vocoids.

3. † Lower intraoral pressure of initial plosive [k].

4. † Higher intraoral pressure of final plosive [t].

5. Longer myodynamic duration of occlusion of the final plosive and corresponding longer acoustic duration of the same plosive.

It is important to note that [t] in /ki'taab/ is the

Table 5.5 Myodynamic, Aerodynamic and Acoustic Measures of Bisyllabic Words containing Stressed Versus Unstressed Syllables

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Myodynamic timing in msec of the first syllable									
(a) T1 between occlusion offset of the initial plosive and occlusion onset of the final plosive									
/'kitab/	85	80	95	85	85	85	85	4	† ** 0.026
/ki'taab/	85	80	75	75	65	80	75		
(b) T2 between occlusion offset of the initial plosive and occlusion offset of the following plosive									
/'kitab/	135	130	140	120	130	125	130	7.5	(-) less than 0.132
/ki'taab/	140	130	150	140	130	140	140		
2. Duration of V.Fs adduction of vocoids of the first syllable in msec									
/'kitab/	45	35	40	40	40	40	40	4	† ** 0.026
/ki'taab/	40	35	30	30	25	35	30		
3. Occlusion duration of the final plosive of the first syllable in msec									
/'kitab/	50	50	45	35	45	40	45	1	** 0.004
/ki'taab/	55	50	75	65	65	60	60		
4. Peak Po of the initial plosive of the first syllable in cm H_2O									
/'kitab/	11	11	12	12	12	10.5	11.4	4.5	† ** less than 0.042
/ki'taab/	11.5	10.5	10	10	10.5	10.5	10.5		

Table 5.5 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
5. Peak Po of the final plosive of the first syllable in cm H_2O									
/'kitab/	11.5	11.5	12	11	11.5	10	11.2	5	† ** 0.042
/ki'taab/	12.5	11.5	12.5	12.5	11.5	13	12.2		
6. Acoustic duration of vocoid of the first syllable in msec									
/'kitab/	70	55	60	55	55	65	60	4.5	† ** less than 0.042
/ki'taab/	65	50	40	45	30	50	45		
7. Acoustic duration of intervocalic contoid in msec									
/'kitab/	40	40	45	30	30	35	35	2	** 0.008
/ki'taab/	45	45	50	45	65	45	50		

final plosive of the first unstressed syllable /kit/ and at the same time it is the initial plosive of the second stressed syllable /'taab/. Again [t] in /'kitab/ is the final plosive in the stressed syllable /'kit/ and the initial plosive in the second unstressed syllable /tab/.

From these findings one may speculate that the shorter acoustic duration of vocoid of the first unstressed syllable in /ki'taab/ may well be ascribed to the advanced closure time of the final plosive [t] which begins the second stressed syllable. For further discussion of this point see Chapter Six, Section 6.5.3.

5.4.5 Geminate Versus Non-geminate Plosives

Table 5.6 deals with the investigation of the myodynamic and aerodynamic correlates of vocoid duration when preceding geminate versus non-geminate contoids. It consists of ten items: each item comprises myodynamic, aerodynamic and acoustic measures of bisyllabic words in minimal pairs containing intervocalic geminate versus non-geminate voiceless plosives. The minimal pair compared is /fat'taat/ versus /fa'taat/.

This table shows the following results:

1. Item 1 shows that both T1 and T2 of the first syllable show very significant differences, suggesting an earlier occlusion onset of [tt] than that of [t].

2. The duration of vocal folds adduction of vocoids shown by item 2 to be very significantly longer for the first syllable when non-geminate [t] follows than that when geminate [tt] does. This is conistent with Tl in the sense that the longer Tl, the longer the duration of vocal folds adduction.

3. Item 3 shows that the myodynamic duration for the final plosive occlusion of the first syllable is very significantly longer for the geminate [tt] than for the non-geminate [t].

4. Item 4 shows that the overall word myodynamic timing is very significantly longer for /fattaat/ than for /fataat/.

5. Items 5 and 6 show that neither Uo nor Po at Ac mimimum of the initial fricative of the first syllable shows any significant differences.

6. Item 7 shows that Po of the final plosive of the first syllable is significantly higher for [tt] than for [t].

7. The acoustic duration of the vocoid of the first syllable is shown by item 8 to be significantly longer when preceding [t] than when preceding [tt] showing the same trend as found in Chapter Four (see Section 4.3.5).

8. Item 9 shows that the acoustic duration of the final plosive of the first syllable is very significantly longer for [tt] than for [t]. This is consistent with the duration

of the myodynamic occlusion of the same plosives as shown by item 3.

9. The word overall myodynamic timing is shown by item 10 to be very significantly longer for /fat'taat/ than for /fa'taat/. This is consistent with the overall myodynamic timings of the same words as shown by item 4.

From the results shown by this table, it seems evident that the intervocalic geminate plosive is characterized by the following myodynamic, aerodynamic and acoustic correlates:

1. Longer myodynamic occlusion duration.

2. † Higher intraoral pressure.

3. Advanced closure time and hence shorter T1.

4. † Short duration of vocal folds adduction of the preceding vocoids.

5. † Shorter acoustic duration of the preceding vocoid.

6. Longer duration of acoustic closure.

On the other hand, the corresponding non-geminate [t] is characterized by the following correlates:

1. Shorter myodynamic occlusion duration.

2. † Lower intraoral pressure.

3. Delayed closure time and hence longer Tl.

4. † Longer duration of vocal folds adduction of the preceding vocoids.

5. † Longer acoustic duration of the preceding vocoid.

6. Shorter duration of acoustic closure.

These results might appear to suggest that the shorter duration of vocal folds adduction† and hence the shorter acoustic duration of vocoids† are compensated by the longer myodynamic duration of occlusion and hence the longer duration of acoustic closure. However, this is ruled out by the fact that the word overall myodynamic timing as well as the word overall acoustic timing are very significantly longer for /fat'taat/ than for /fa'taat/. In accordance with these findings, then, one could speculate that the shorter acoustic duration of vocoids† preceding geminate plosives in I.S.A. can be well ascribed to the interaction between the above mentioned myodynamic and aerodynamic correlates associated with the production of geminate versus non-geminate plosives. For further discussion of this see Chapter Six, Section 6.6.3.

Table 5.6 Myodynamic, Aerodynamic and Acoustic Measures of Bisyllabic Minimal Pair Words containing Geminate Versus Non-geminate Contoids

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
1. Myodynamic timing of the first syllable in msec									
(a) T1 between Ac minimum of the initial fricative and occlusion onset of the final plosive									
/fat'taat/	110	95	110	95	95	95	100	4 †	** 0.026
/fa'taat/	110	100	155	120	115	110	120		
(b) T2 between Ac minimum of the initial fricative and occlusion offset of the final plosive of the first syllable									
/fat'taat/	260	240	265	235	220	235	240	0	** 0.002
/fa'taat/	175	155	185	165	180	180	175		
2. Duration of V.Fs adduction of vocoid of the first syllable in msec									
/fat'taat/	60	45	40	40	40	30	40	5.5 †	* less than 0.064
/fa'taat/	45	55	70	50	45	60	55		
3. Myodynamic duration in msec of the final plosive occlusion of the first syllable									
/fat'taat/	145	145	135	140	125	140	140	0	** 0.002
/fa'taat/	65	55	30	45	65	70	55		

Table 5.6 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
4. Word overall myodynamic timing in msec between Ac minimum of the initial fricative and occlusion offset of the final plosive									
/fat'taat/	445	430	435	420	390	410	420	0.5	** less than 0.004
/fataat/	360	340	390	360	350	360	360		
5. Uo at Ac minimum of the initial fricative of the first syllable in L/m									
/fat'taat/	30	30	12	55	16	18	26.8	16.5	(-) less than 0.938
/fataat/	8	18	30	48	30	30	27.3		
6. Po at Ac minimum of the initial fricative of the first syllable in cm H_2O									
/fat'taat/	7	4	3.5	3.5	6	8	5.3	10.5	(-) less than 0.240
/fa'taat/	10	9	7	6	5	4	6.8		
7. Peak Po of the final plosive in cm H_2O of the first syllable									
/fat'taat/	13	10	10	12	12	13	11.6	6	* 0.064
/fa'taat/	11	11	10	9.5	9.5	10	10.2		
8. Acoustic duration of vocoid of the first syllable in msec									
/fat'taat/	60	45	55	45	50	40	50	6	* 0.064
/fa'taat/	60	60	110	50	50	80	70		

Table 5.6 continued

Utterances	Tokens 1	2	3	4	5	6	Av	U	p
9. Acoustic duration in msec of the final plosive of the first syllable									
/faˈttaat/	140	130	120	140	130	125	130	0	** 0.002
/faˈtaat/	55	55	25	40	65	65	50		
10. Word overall acoustic timing in msec(1)									
/faˈttaat/	460	435	445	430	400	430	435	2	** 0.008
/faˈtaat/	405	360	420	365	365	360	380		

(1) Measurements were made on duplex oscillogram from acoustic closure onset of the word initial plosive to the acoustic closure offset of the word final plosive.

CHAPTER SIX

DISCUSSIONS AND CONCLUSIONS

6.1 Intrinsic Duration

6.1.1 Summing Up of the Acoustic Data

Our acoustic investigation of the durational differences in open versus close (long and short, back and front) as well as in long versus short (close and open, back and front) vowels of I.S.A. showed the following results:

1. All open vowels are very significantly longer than their corresponding close vowels no matter whether they are long or short, back or front, rounded or unrounded. The longer duration is dependent on the degree of openness; the opener the vowel, the longer its duration i.e. open > half open to half close > close, e.g. /aa/ > /oo/ > /uu/.

2. All long vowels are very significantly longer than short vowels no matter whether they are open, close, back, front, rounded or unrounded. (For more details see section 4.3.1).

6.1.2 Summing Up of the Myodynamic and Aerodynamic Data:

Our myodynamic and aerodynamic investigation showed the following results:

1. Open versus close vowels:

(a) The timing of executing Ac min. is always delayed when open vowels precede i.e. longer myodynamic timing for words having open vowels than those having close vowels.

(b) This delay is accompanied by greater duration of vocal folds adduction for open vowels than that for close vowels.

(c) No significant differences were shown by the myodynamic duration of the supraglottal constriction, Ac min. and acoustic duration of the final fricative, nor were there any striking differences in the aerodynamic correlates, Uo and Po, of the same final fricative.

2. Long Versus Short Vowels

(a) Longer duration of vocal folds adduction for long vowels than for short vowels.

(b) The longer the duration of vocal folds adduction for long vowels, the shorter the myodynamic duration of the supraglottal constriction for the following fricatives. This converse relation was also shown for short vowels i.e. the shorter the duration of vocal folds adduction, the longer the myodynamic duration of the supraglottal constriction for the following fricative.

(c) From the acoustic point of view and for the same utterance, the results showed the same trend as (b); the longer the vocoid duration for long vowels, the shorter the acoustic duration for the final contoid and the shorter the vocoid duration for short vowels the longer the duration for the final contoid.

(d) Neither the myodynamic timing nor the overall acoustic timing of the words in question, i.e. words differing only in vowel length, showed any significant differences.

(e) No significant difference was shown by Ac min.; nor were there any striking differences in the aerodynamic correlates, Uo and Po, for the final fricative. (For more details see section 5.4.1).

6.1.3 Discussion

In the literature on vowel duration many questions are raised concerning the acoustic durational variations of vowels and linguists are continually seeking appropriate answers; some of these answers are being sought in the phonetic facts and others in the phonology of the investigated languages. One of the questions raised in this study is whether the acoustic durational differences found in open versus close and long versus short vowels in I.S.A. are physiologically conditioned or imposed by the phonology of the language. In other words, whether these durational differences are inherent in the physiological process and hence constitute a universal phonetic phenomenon or whether they are phonologically conditioned and deliberately maintained by the speaker and hence constitute a language-specific phenomenon. Our myodynamic, aero-dynamic and acoustic investigations have shown that the acoustic variations of open versus close vowels can be ascribed to physiologically inherent factors whereas those of long versus short vowels can be ascribed to phonologically imposed factors as we shall see in the following argument.

The results shown in Table 5.2.1 and the time delay in executing the constriction of /s/ when open vowels precede (short and long) suggest that certain articulatory constraints do require that delay to occur though, from the experimental point of view, it is not within the capacity of this study to pinpoint these constraints. However, one may speculate that the most likely candidates could be tongue height and mandibular movement since both the preceding vowel and the following consonant[1] are articulated at the front of the vocal tract. This is compatible with the hypotheses suggested by House & Fairbanks (1953), House (1961), Lindblom (1967), Lehiste (1970) and Condax & Krones (1976) as reviewed in section 2.2 whose data showed that tongue height and the movement

(1) This applies for the particular contexts investigated on the myodynamic, aerodynamic and acoustic levels, i.e. /daas/, /das/, /diis/ and /dis/ included in Table 5.2.1.

of the lower jaw are decisive in delaying the constriction of the following consonant and consequently prolonging the preceding open vowels.

In the light of these assumptions, it is plausible to think that the distance moved by the tongue from the static position during the articulation of open vowels to the denti-alveolar region of the palate where it accomplishes the constriction for [s] is longer than that in the case of close vowels. Hence longer duration of vocal folds adduction for open vowels is necessary to cope with the delay in the timing of accomplishing that constriction. In accordance with this myodynamic (articulatory) based assumption, it is also plausible to think that the longer acoustic duration of open vowels is consistent with that longer distance moved by the tongue and the corresponding phonatory state maintained by the vocal folds for open vowels. The explanation, then, in terms of the articulatory distance hypothesis put forward by Jesperson and advocated by House & Fairbanks (op. cit.), Maak (1953), Fischer Jørgensøn (1964) and Lindblom (op. cit.) (see section 3.2.1) seems to be a feasible explanation of why open vowels are longer than close vowels in these particular contexts of I.S.A.; the articulatory movement here is a decisive factor; the longer the articulatory movement moved by the tongue to accomplish the supraglottal constriction for the following fricative, the longer the acoustic duration of the preceding vowel.

In the case of long versus short vowels it is entirely different; the distance moved by the tongue in accomplishing the constriction for the following fricative is presumably the same when both a long and short vowel precede. But despite this similar timing, the duration of vocal folds adduction for long vowels is considerably longer than that for short vowels and is accompanied by a substantial shortening of the supraglottal constriction for the following consonants. In the case of short vowels it is quite the opposite; shorter duration of vocal folds adduction is accompanied by a substantial lengthening of the following supraglottal constriction. It is, then, not feasible to explain the lengthening of long vowels in the same terms as the explanation of the lengthening of open vowels, especially when we consider the fact that both /diis/ and /das/ are very significantly longer than /dis/. As House (1961) put it, 'vowel duration increases as tongue height increases in one case and as tongue height decreases in the other.'(1) (op. cit., p.1177).

A question may be asked; if it is not the articulatory distance moved by the supraglottal articulators, as in open versus close vowels, that determines the durational difference between long versus short vowels, what then determines that difference? Further inspection of Table

---

(1) See vowel diagram for details of vowel quality. Incidentally, this may lead to the conviction that in the case of /ii/ versus /i/ in I.S.A. both length and phonetic quality interact to bring about the phonological distinction. Nevertheless it seems to us that length is so vital an element in I.S.A. that phonological distinction is possible even when no change in quality occurs. See Section 1.2.

5.2.2 reveals a clear indication of a temporal compensatory adjustment between the glottal and supraglottal timings as shown by the duration of vocal folds adduction of vocoids and myodynamic duration of supraglottal constriction. This compensation is clearly seen on the acoustic level as well; longer vocoid followed by shorter contoid and vice versa. Despite these differences in the timings of the glottal and supraglottal gestures, neither the myodynamic nor the acoustic overall word timing showed any significant difference. It is also worth observing that the aerodynamic conditions created during the production of the final fricative [s] do not take any vital part as shown by the lack of striking differences in the airflow and pressure in the same table. The hypothesis of temporal compensatory adjustment between the duration of a vowel and that of a following consonant based on these data is a feasible explanation of the durational behaviour of long versus short vowels in these particular monosyllabic minimal pair words in I.S.A. It also seems that this temporal compensatory adjustment is carefully planned at a higher linguistic level and deliberately maintained by the speaker for phonological objectives, i.e. it has nothing to do with the physiological process that is responsible for the durational differences in open versus close vowels. This lends evidence to the statement by Lehiste (1971) that the word can possibly be regarded as a phonological unit (see section 3.2.5).

What lends further support to our hypothesis is the fact that from the perceptual point of view the acoustic durational differences of open versus close vowels hover around the DLs suggested by Lehiste (1970) (see section 4.4) whereas those in long versus short vowels are well above these threshhold values. From the results shown in Table 4.3.1, if we pool all the vowel environments the average acoustic durational difference between open and close vowels (i.e. /daas/ versus /diis/ and /das/ versus dis) is 40 msec whereas that between long and short vowels (i.e. /daas/ versus /das/ and /diis/ versus /dis/ is 60 msec. See also Table 4.8 and Figure 4.15 for absolute DLs at different reference duration in comparison with Henry's (1948) data for both categories.

This strongly suggests that the average durational difference between open and close vowels is significant only from the speaker's point of view, though it may be perceived by the listener i.e. it seems likely to be phonetically significant whereas those between long and short vowels, are significant from the point of view of both the speaker and the listener, i.e. they are not only phonetically but also phonologically significant.

This hypothesis also sheds considerable doubt on whether the term intrinsic duration should cover both dimensions open/close and long/short in I.S.A. This term as suggested by Lehiste (1970, p.18) (see section 2.2.1) only refers to the duration of a vowel as determined by its phonetic quality and does not seem adequate to refer to the durational difference between long and short vowels. It is true that a quality difference does occur between long and short vowels in I.S.A. (see section 1.2) but the durational difference between these vowels is not phonetically determined, i.e. it is not inherent in the physiological process as it appears from the foregoing argument.

It is also worth observing that, in so far as the data available in this study are concerned, there is no indication whether long vowels in I.S.A. are tense and short vowels are lax as suggested by Thomas (1947), Chomsky & Halle (1968), House (1961), and Jones (1976) for English (see section 3.2.2.1).

6.1.4 Conclusions

For these particular phonetic contexts of I.S.A. investigated from the myodynamic, aerodynamic and acoustic points of view our conclusions could be summarized as follows:

(a) Open Versus Close Vowels

1. The longer duration of open vowels could be ascribed to the longer articulatory distance taken by the tongue

to accomplish the constriction of the following contoid. Tongue height and mandibular movement are assumed to take part in delaying the tongue as it accomplishes that constriction.

2. It is evidence that the acoustic durational difference between open and close vowels is physiologically determined and hence may constitute a phonetic universal phenomenon.

3. It seems that the durational difference between open and close vowels is only phonetically significant, and is likely to have little perceptual value and no consequential phonological significance.

(b) Long Versus Short Vowels

1. The acoustic durational difference between long and short vowels could be ascribed to a temporal compensatory adjustment between the duration of vocal folds adduction of the preceding vocoids and the myodynamic duration and time of onset of the supraglottal constriction of the following contoid, which is planned at a higher linguistic level and deliberately maintained by the speaker for phonological objectives.

2. This durational difference is not inherent in the physiological process and hence constitutes a language specific phenomenon in I.S.A.

3. This durational difference is phonologically as well as phonetically significant.

6.2 Voicing/Voiced Versus Voiceless Consonants

6.2.1 Summing Up of the Acoustic Data

Our acoustic investigation on the durational differences of vocoids when followed by voiced versus voiceless contoids in I.S.A. showed the following results:

1. All vocoids preceding voiced fricatives are very significantly longer than those preceding voiceless fricatives.

2. All vocoids preceding voiced plosives are very significantly longer than those preceding voiceless plosives.†

3. Levels of significance as well as average durational differences of vocoids are considerably higher when voiced versus voiceless fricatives follow than when voiced versus voiceless plosives do. (For more details see section 4.3.2).

6.2.2 Summing Up of the Myodynamic and Aerodynamic Data

Our myodynamic and aerodynamic investigation showed the following results:

1. Voiced Versus Voiceless Fricatives

(a) Volume airflow rate (Uo) and intra oral pressure (Po) are very significantly higher for [s] than for [z].

(b) The minimum cross-sectional area of constriction, Ac min., is very significantly smaller for [z] than for [s].

(c) The minimum cross-sectional area of constriction, Ac min., is executed at the same time for both [z] and [s], i.e. myodynamic timing is the same.

(d) Neither the duration of the vocal folds adduction of the preceding vocoid nor the myodynamic duration of the supra-glottal constriction of the following fricative showed any significant differences.

(e) The acoustic duration of the final fricative included in the same table is very significantly longer for [s] than for [z].

2. <u>Voiced Versus Voiceless Plosives</u>

(a) Intra oral pressure is very significantly higher for [t] than for [d].

(b) The timing of the occlusion onset for [t] is the same as that for [d], i.e. the myodynamic timing (T_1) is the same.

(c) The duration of the vocal folds adduction is the same for vocoids when preceding both [t] and [d].

(d) Neither the duration of the vocal folds adduction of vocoids nor the myodynamic duration of the supraglottal constriction of the following plosive (closure duration) showed any significant differences.

(e) The acoustic duration of the following plosive (acoustic closure) included in the same table was shown to be very significantly longer for [t] than for [d]. (For more details see sections 5.4.2.1 and 5.4.2.2).

6.2.3 Discussion

The question why vowels are longer before voiced than before voiceless consonants has been one of the most difficult questions confronted by phoneticians in recent years. Many explanations for this particular acoustic aspect of vowel duration have been suggested, as reviewed in Chapter Three. The question whether these durational differences constitute a phonetic-universal or language-specific phenomenon has also been tackled. The task undertaken in this study is to see which of these explanations is valid to interpret these durational differences in I.S.A. in so far as the available data are concerned.

The hypothesis of anticipating more articulatory effort for voiceless consonants suggested by Belasco (1953) and Delattre (1962) (see section 3.2.2) is discarded here as a possible explanation because, as attested by our results, the timing of the minimum cross-sectional area of constriction is accomplished at the same time when both

[s] and [z] follow; this also applies for the timing of occlusion onset as regards [t] and [d]. Moreover, the minimal area of constriction for [z] is shown to be very significantly smaller for [z] than for [s]; if anything, [z] needs more articulatory effort to achieve and maintain that small area not less. Furthermore, the myodynamic duration of [s] and [z] as well as the myodynamic closure duration of [t] and [d] are shown to be the same.

This also sheds considerable doubt on the hypothesis of Malécot (1970) (see section 3.2.2.1) that we shorten vowels before voiceless consonants because of anticipating higher intra oral pressure. Although [s] and [t] are characterised by higher intra oral pressure, both the time of executing their constriction and the duration of vocal folds adduction of the preceding vowels are the same as those of [z] and [d] respectively.

It is also worth observing that in so far as the laryngographic data available in this study are concerned, there is no indication of a particular laryngeal adjustment for voiced consonants as suggested by Halle & Stevens (1967) (see section 3.2.4) that necessitates a longer preceding vowel. It is true that the Gx trace showed two different forms for voiced and voiceless consonants, level 3 and 4 respectively (see section 5.2.3.1 and Fig. 5.2), but the transition timing from a vowel to a following consonant seems to be the same no matter whether the consonant is voiced or voiceless as suggested by the non-significant differences of the duration of vocal folds adduction measured on level 2 (see section 5.3.4). That is if the delicate laryngeal adjustment for voiced consonants were, as assumed, to require more time than the simpler, less delicate adjustment in the case of voiceless consonants, the duration of vocal folds adduction of the preceding vocoid should have shown significantly longer duration before voiced than before voiceless consonants.(1)

Our data also do not agree with the hypothesis suggested by Kozhevnikov & Chistovich (1967) (see section 3.2.5), that the longer duration of vowels preceding voiced consonants are compensated for by shortening the closure duration of that consonant and vice versa in the case of voiceless consonants. As attested by our results, neither the myodynamic duration of the supraglottal constriction of the final contoid nor the duration of vocal folds adduction of the preceding vocoids has shown any significant differences for both categories; [s] versus [z] and [t] versus [d] i.e. from the myodynamic point of view the temporal compensatory adjustment between a vowel and a following consonant is ruled out. Our data also do not agree with the closure transition hypothesis suggested

---

(1) Still, we cannot totally rule out the plausibility of this hypothesis with the available data, because to do so, one needs to investigate the glottal closure/aperture to see whether the vocal folds are abducted for voiceless consonants earlier than for voiced consonants. This would have shown whether the transition time from the adducted state to the abducted state of the vocal folds is longer for voiced consonants than for voiceless ones.

by the same writers and advocated by Chen (1970) since the occlusion onset timing for the final plosive is the same for both [t] and [d].

In the light of the above arguments, it does not seem feasible to interpret the acoustic durational differences of vowels preceding voiced versus voiceless consonants in purely myodynamic terms. Our results strongly suggest a very vital role played by the aerodynamic conditions, airflow and intra oral pressure, above the glottis, behind the supraglottal constriction created by the glottal adjustment which is different in the case of voiced from that of voiceless consonants.(1) If we have another look at Table 5.3.1 we can see that the most significant differences are those shown by airflow and intra oral pressure where they are very much higher for [s] than for [z] as well as the inferred Ac min. where it is very significantly smaller for [z] than for [s]. Furthermore, we can also see that the very significant differences of acoustic durations for the preceding vocoids and following consonants (fricatives and plosives, see also Table 5.3.2) do not have, on the myodynamic level, any corresponding significant differences for the duration of vocal folds adduction of the preceding vocoids and the myodynamic duration of the supraglottal constriction

---

(1) As reviewed in the literature the glottis is taken to be larger in the case of voiceless consonants and smaller in the case of voiced consonants.

of the following consonant. That is, the observed acoustic differences cannot be ascribed to the myodynamic programme for the glottal or supraglottal articulation which showed similar values. They might be attributed to the contrasting aerodynamic conditions created behind the constriction of [s] versus [z] and [t] versus [d] by the glottal aperture/closure, assuming that the sub-glottal pressure is the same for both sounds as found by Slis (1970) and assumed by Scully (1970, 1974 and 1979). (See section 3.2.3) Scully (1974) states:

> "It is possible, however, to explain durational differences for vowel-consonant sequences with voiced voiceless consonants on the assumption that subglottal pressure and supraglottal articulator actions are the same for both. The observed aerodynamic differences can arise directly as a result of the single glottal articulatory distinction while the observed acoustic differences arise as a result of the aerodynamic conditions and not directly from the myodynamic articulatory state of speech production." (op. cit., p.228).

What is interesting in this argument is that for the present speaker of I.S.A., in this context, the speaker maintains a smaller area for [z] than for [s] unlike the case reported in Scully (1979) where the speaker maintained the same Ac min. for both [z] and [s] (see section 3.2.3). It is speculated that I.S.A. has a more fully voiced [z] than the English [z] reported by Scully. Consequently we may expect different aerodynamic conditions (pressure and airflow) arising in I.S.A. and English in the production of the fricatives in question. These different aerodynamic conditions may well be the result of a combination of smaller glottal area and supraglottal (tongue constriction) area for I.S.A. [z] as opposed to English [z]. This also may explain why [z] in I.S.A. has a lower noise component than [s] on spectrogram in intensity as well as in duration. In a computer model of speech production considering the aerodynamic, myodynamic and acoustic requirements for voiced and voiceless fricatives, Scully (1975) states that if AG max. (maximum glottal area) is large, stronger frication noise is predicted with a larger Ac min. (minimum constriction area). The basic theoretical explanation here is that a larger glottal area in the fricative will give longer and stronger noise than a smaller glottal area.

In consequence, her modelling predicts more noise for English [s] than for [z] which may also apply for I.S.A. [s] and [z]. However, [s] and [z] noise could differ by different amounts in the two languages. We expect voicing and frication to be at each other's expense. Roughly speaking, we expect I.S.A. [z] which is fully voiced to have less frication noise than English [z]. Also I.S.A [s] might possibly have less frication noise than English [s] though these two might well be similar and could even be reversed.

As for /baat/ versus /baad/ and /bad/ versus /bat/ included in Table 5.3.2 the acoustic durational differences† of the preceding vocoids can also be ascribed to the contrasting values of intra oral pressure of [t] and [d], since these acoustic durational differences, as well as those of the following contoids, have no corresponding differences on the myodynamic level.

From the perceptual point of view these durational differences† of vocoids hover around the DLs values (see Table 4.8 and Figure 4.15 as well as Sections 2.6 and 4.4 for DLs values suggested by Lehiste 1970). Consequently, they are not likely to be perceptually and phonologically striking as are those in English as found by Denes (1955) and Chen (1970) (see Section 2.3.1). Hence, they are considered to be phonetically† but probably not phonologically significant.

In accordance with the foregoing arguments we agree with Chen (1970) and Scully (1979) (see Sections 2.3.1 and 3.2.3) in presuming that the acoustic durational variations of vowels as a function of the voicing of the following consonant could be a language universal phenomenon, but the extent to which a following voiced or voiceless consonant affects these durational variations of the preceding vowels is determined by the language specific phonological structure.

6.2.4 Conclusions

For these particular phonetic contexts of I.S.A. investigated on the myodynamic, aerodynamic and acoustic levels, our conclusions may be summarized as follows:

1. The observed acoustic durational differences of vowels preceding voiced versus voiceless consonants can be ascribed to the contrasting aerodynamic conditions created behind the supraglottal constriction by the glottal adjustment which must be different in the case of voiced from that of voiceless consonants and not directly to the myodynamic contrast.

2. Since these contrasting aerodynamic conditions are actually created by a corresponding myodynamic (laryngeal) contrast, they are physiologically determined and hence may constitute a phonetic universal phenomenon. On the other hand, if vowel duration is crucial for perception as in English, it could be myodynamically adjusted for phonological objectives.

6.3 Manner of Articulation/Emphatic Versus Non-Emphatic Consonants

6.3.1 Summing Up of the Acoustic Data

Our acoustic investigation into variations in vocoid duration when followed by emphatic versus non-emphatic consonants showed the following results:

1. All vocoids preceding emphatic fricatives are either significantly or very significantly longer than those preceding non-emphatic fricatives.

2. All vocoids preceding emphatic plosives are very significantly longer than those preceding non-emphatic plosives. For more details see Section 4.3.2.

6.3.2 <u>Summing Up of the Myodynamic and Aerodynamic Data</u>

Our myodynamic and aerodynamic data showed the following:

(a) Emphatic Versus Non-emphatic Fricatives.

1. The timing of executing Ac min., the minimum cross-sectional area of constriction for [s̲] is delayed more than that for [s].

2. The duration of vocal folds adduction is very significantly longer for vocoids preceding [s̲] than for those preceding [s].

3. Neither intra oral pressure nor airflow shows any significant differences between [s] and [s̲].

4. Neither the myodynamic nor the acoustic durations of [s̲] and [s] shows any significant differences.

(b) Emphatic Versus Non-emphatic Plosives.

1. The timing of occlusion onset is delayed for [t̲] more than that for [t].

2. The duration of vocal folds adduction is significantly longer for vocoids preceding [ṯ] than for those preceding [t].†

3. Intra oral pressure is shown to have no significant differences between [ṯ] and [t].

4. The myodynamic duration of occlusion is shown to be very significantly longer† for [ṯ] than for [t] when long vowels precede e.g. /baaṯ/ versus [baat] but not significantly different when short vowels precede e.g. /baṯ/ versus /bat/. (For more details see Sections 5.4.2.3 and 5.4.2.4).

6.3.3 Discussion

The most salient articulatory feature of Arabic emphatic consonants as agreed by many phoneticians is that they are characterized by two types of constriction. Abercrombie (1967) calls them primary and secondary articulations and states that:

> "... the secondary articulation is a stricture of open approximation of the articulators, and as such involves less constriction of the vocal tract than the primary stricture."
> (op. cit., p.62).

Odisho (1973) suggests that the same primary stricture is retained for the emphatic and their counterparts non-emphatic consonants and, 'the only difference lies in an additional secondary stricture.' (op. cit., p.18).

There is almost unanimous agreement among the phoneticians who have investigated this particular phenomenon in Arabic that the most evident feature characterizing this secondary articulation is the constriction of the pharynx, whence the term pharyngealization as suggested by Abercrombie (1967) and Al-Ani (1970). Marcais (1948) as reviewed by Odisho (1975) made a study of this phenomenon in Arabic, supported by X-ray tracing, which showed:

> "the projection of the root of the tongue toward the back wall of the pharynx and the resulting reduction of the pharyngeal cavity. (op. cit., p.353).

Ali and Daniloff (1972) made a cinefluorographic study which showed that:

> "In all cases when emphatic consonants are articulated, the tongue exhibits a simultaneous slight depression of the palatine dorsum and a rearward movement of the pharyngeal dorsum toward the posterior pharyngeal wall." (op. cit., p.639).

One of the questions raised in this study is why vowels are longer before emphatic than before non-emphatic consonants as shown by our acoustic results, a problem which has never been investigated in such detail before. The emphatic and their counterpart non-emphatic consonants selected for investigation in this study are denti-alveolar fricatives and plosives. Odisho (1975) specifies the articulatory features involved in the production of these consonants and states:

> "the tip of the blade of the tongue is raised towards the denti-alveolar or the alveolar zones to execute the primary stricture. And as the back-root of the tongue is simultaneously required to move rearward towards the posterior pharyngeal wall, the tongue undergoes two antagonistic manoeuvres." (op. cit., p.357).

If we go back to our myodynamic and aerodynamic results, we can see that the most obvious correlate is the delay in the timings of executing the supraglottal constriction for [s̱] and [ṯ], which is accompanied by a corresponding delay in the timing of abducting the vocal folds when these emphatic consonants follow. We have no alternative here but to interpret the longer acoustic duration of vowels preceding these emphatic consonants in terms of a logner articulatory distance taken by the tip of the blade of the tongue to move from the position assumed during the production of vowels to execute the primary constriction at the denti-alveolar region. It seems plausible to speculate that the main cause of delaying the execution of the primary constriction of [s̱] and [ṯ] is the rearward movement undergone by the back-root of the tongue towards the posterior pharyngeal wall, an articulatory feature required to distinguish the emphatic consonants from their non-emphatic counterparts, specified earlier in this section as a secondary articulation. To be more specific, it is the movement towards the secondary constriction that is to be started first and not that towards the primary constriction as implied by Odisho (op. cit.) in the quotation above and explicitly stated by him on another page of the same reference viz that:

> "... the primary stricture must be properly retained while the rearward gesture is executed." (Our emphasis) (Op. cit., p.349).

Our data suggest quite the opposite; it is the secondary constriction that should be properly retained while the tip of the tongue moves toward the denti-alveolar region to accomplish the primary constriction, otherwise the timing of executing the primary constriction for [s̱] and [ṯ] should have shown similar values as those for [s] and [t] respectively, i.e. the same myodynamic timing for /baas̱/ versus /baas/ and /baaṯ/ versus /baat/.†

What supports our hypothesis even further is the fact that the vowel preceding the emphatic consonants undergoes a simultaneous qualitative change besides the already observed quantitative difference; it is lower and more back than that preceding non-emphatic consonants. In consequence, if the rearward movement of the back-root of the tongue were to be executed, as assumed by Odisho (op. cit.) after the primary constriction of the following emphatic consonant had been properly retained, the preceding vowel should not have undergone such qualitative and quantitative changes. This also sheds some light on the controversial issue whether the vowel or the consonant is the main domain of the emphatic feature of Arabic. It does seem evident here that the preceding vowel is as affected by this secondary constriction as the following consonant i.e. the phonetic exponents of the emphatic feature in Arabic are not confined to either the consonantal or the vocalic segment but stretch over both or probably over the whole syllable.

From the perceptual point of view, however, the durational differences of vowels preceding emphatic versus non-emphatic consonants hover around the Dls values and consequently have little or no consequential value from the listener's point of view i.e. they are phonetically but probably not phonologically significant. Nevertheless, the longer duration before the emphatic consonants might possibly contribute to the phonological distinction between the emphatic and their counterpart non-emphatic consonants, interacting with the other exponents of the emphatic feature.

6.3.4. Conclusions

For these particular phonetic contexts of I.S.A., investigated on the myodynamic, aerodynamic and acoustic levels, our conclusions can be summarized as follows:

1. The longer acoustic durations of vowels before emphatic consonants than those before non-emphatic consonants can be ascribed to the delay in the articulatory movement traversed by the tip of the blade of the tongue to execute the primary constriction at the denti-alveolar region in the case of emphatic consonants. This is probably needed to allow time for the rearward movement of the back-root of the tongue towards the posterior pharyngeal wall achieved to execute the secondary constriction of the emphatic consonants.

2. These observed durational differences are only phonetically significant but they could interact with the other phonetic exponents of the emphatic feature to bring about the phonological distinction between the emphatic and their counterpart non-emphatic consonants.

6.4 Place of Articulation

6.4.1 Summing Up of the Acoustic Data

Our acoustic investigation on the durational differences of vocoids associated with the different places of articulation of the following contoid showed the general trend that all vocoids preceding back contoids are very significantly shorter than those preceding front and central contoids.(1) The results were shown in this order:

A. With Open Vowels

1. Vocoids are very significantly shorter before voiceless pharyngeal fricatives than before voiceless labio-dental, denti-alveolar, palato-alveolar and uvular fricatives.

2. Vocoids are very significantly shorter before voiced pharyngeal fricatives than before voiced denti-alveolar and uvular fricatives.

3. Vocoids are very significantly shorter before the glottal plosive (glottal stop) than before voiceless denti-alveolar and uvular plosives.

---

(1) For the purpose of a convenient discussion of our data the term front stands for labio-dental, denti-alveolar and palato-alveolar consonants, the term central stands for uvular consonants, and the term back stands for pharyngeal and glottal consonants.

4. In so far as the level of significance is concerned, no consistent pattern was shown among the other members of each group but according to their average values they showed the following tendencies:

(a) Voiceless fricatives; denti-alveolars > palato-alveolars > labio-dentals > uvulars > pharyngeals.

(b) Voiced fricatives; denti-alveolars > uvulars > pharyngeals.

(c) Voiceless plosives; uvulars > denti-alveolars > glottals.

B. <u>With Close Vowels</u>

Vocoids before front versus back contoids (voiceless denti-alveolar versus voiceless pharyngeal fricatives) showed the same trend as open vowels but with considerably lower levels of significance as well as of average durations.

On the other hand, in so far as the place of articulation of the vowel itself is concerned no consistant or striking effects on vocoid duration were shown by our acoustic results. (For more details see Section 4.3.3.)

6.4.2 Summing Up of the Myodynamic and Aerodynamic Data

Our myodynamic and aerodynamic investigation showed the following results:

1. A delay in executing the constriction of the final contoid is always accompanied by a longer acoustic duration of the preceding vocoid i.e. the longer the myodynamic timing of the test monosyllabic words, the longer the acoustic duration of vocoids and vice versa.

2. The myodynamic timings of the words with final voiceless and voiced pharyngeal fricatives [ħ] and [ʕ] and, consequently, the acoustic durations of their vocoids are always significantly or very significantly shorter than those of the other test words with final front or central contoids. (For more details see Section 5.4.3).

6.4.3 Discussion

In our survey of the literature in Chapter Two we have noticed the fact that the investigations on the durational variations of vocoids associated with different places of articulation of the following contoids have not always yielded consistent pattern (see Section 2.3.2). It is true,however, that the data reported by Zimmerman & Sapon (1958) for Spanish, Peterson &Lehiste (1960) for American English and Fischer-Jørgensen (1964) for Danish have shown some consistent patterning. Delattre (1962) in his review of the two studies of Zimmerman & Sapon (op. cit.) and of Peterson & Lehiste (op. cit.) suggests the hypothesis that their data revealed the fact that vowel duration increases according to the front-to-back pattern of the following consonant. Lehiste (1970) also agrees that the three studies above showed an increase in vowel duration when the post vocalic consonant shifts farther back in the mouth. Nevertheless, the earlier studies by House & Fairbanks (1952) for American English and Maak (1953) for German had shown quite different results as reviewed in Section 2.3.2. Incidentally, one should bear in mind that these studies were made on languages all the consonants of which are articulated at the region between the lips and the velum and no data have been reported in such detail on the influence of glottal and pharyngeal consonants on the preceding vowels in order to complete the whole picture ; for what is considered as a back consonant in the languages investigated by the studies above is no more than a central consonant in a language like Arabic.

Our acoustic investigation showed the fact that all vowels preceding glottal and pharyngeal consonants are very significantly shorter than those preceding front and central consonants in I.S.A.; a fact that contradicts the hypothesis suggested by Delattre (op. cit.) that vowel lengthening is proportional to front-to-back pattern of the following consonant position. As regards the other members of the groups compared in each case (i.e. the front and central consonants), our data shows neither an internally consistent pattern nor any agreement with the data reported by the studies mentioned above, though according to the average values, they show some agreement with those reported by House & Fairbanks (op. cit.).

Our myodynamic and aerodynamic investigation was designed to tackle the question why open vowels are considerably shorter before pharyngeal fricatives than those before front and central fricatives.(1) If we look at Tables 5.4.1 and 5.4.2 the first thing that attracts our attention is the fact that the acoustic duration of vowels and the myodynamic timing of the test monosyllabic words are closely related to each other,i.e. any delay or advancement in the timing of executing the constriction of the following contoid is accompanied by a corresponding longer or shorter duration of the preceding vowel respectively as illustrated in Figures 5.15 and 5.16. This trend is in remarkable agreement with the articulatory distance hypothesis advocated by Fischer-Jørgensen (op. cit.) and Maak (op. cit.) (see section 3.2.1) to interpret why vowel duration varies according to the different places of articulation of the following consonant. They postulate that the duration of the vowel depends (under otherwise equal conditions) on the extent of the movement of the speech organs required and that the farther the point of articulation of a vowel from that of the following consonant, the longer the vowel.

If we go back to our own data illustrated in Figures 5.15 and 5.16 we can infer the fact that the execution of the constrictions of the pharyngeal fricatives are

(1) We have avoided the myodynamic and aerodynamic comparison between words with final glottal stop and the corresponding ones with final front and central plosives because adequate investigation of the laryngeal mechanism is beyond the experimental methods of this study.

accomplishedmore quickly and with more efficiency. This leads to the speculation that certain articulatory constraints do take part in speeding up the execution of the constriction for pharyngeal fricatives on the one hand, and delaying it for front and central fricatives, on the other. The question raised here is what these articulatory constraints could be. What makes the task of answering this question easier is that the vowel investigated here is a long open vowel /aa/. So, one of the articulatory constraints one could think of is the movement of the lower jaw which may have its consequential effect on the tip, the blade and the palative dorsum of the tongue while moving from their static positions assumed during the production of vowels to accomplish the constrictions for the front and central fricatives at particular regions of the upper jaw. For the pharyngeal fricatives the story is quite different, it is the back-root and not the tip, the blade or the palatine dorsum that is involved in accomplishing their constrictions i.e. the lower jaw would no longer interfere with the rearward movement of the back-root of the tongue towards the posterior walls of the pharynx to accomplish the constrictions for the pharyngeal fricatives, resulting in quicker and more efficient constrictions than those accomplished for the front and middle fricatives.

It also seems feasible in this context to speculate that the muscles of the pharynx could possibly constitute an efficient articulatory constraint that participate in speeding up the execution of the constriction for the pharyngeal fricatives. Hardcastle (1976, p.125) states:

> "There is probably some point in considering the pharynx as an active articulator in the vocal tract as its diameter can be altered considerably during speech."

He also states:

> "The lateral dimension of the pharynx can also be varied by the muscles of the pharynx itself which have basically a sphincter function. Isotonic contraction of these sphincter muscles will narrow the pharynx and isometric contraction will serve to tense the wall of the pharynx." (ibid).

It is true, however, that the tip, the blade and the palatine dorsum of the tongue are more mobile than the back-root of the tongue but, as can be inferred from the above argument, the articulatory distance taken by them to execute the constriction for the front and central fricatives is very much longer than that taken by the back-root of the tongue acting synergistically with the sphincter muscles of the pharynx to execute the constriction for the pharyngeal fricatives. Al-Ani (1970, p.60) states:

> "In producing the /ħ/ a constriction is

formed by the dorsum of the tongue
against the posterior wall of the pharynx
where the movements of the pharynx muscles
play an important role."

His X-ray films, however, did not show so clearly the function of these muscles.

Our hypothesis is substantiated even further by the fact that our acoustic data have shown the same trend that vowels are shorter before pharyngeal than before palato-alveolar fricatives (front versus back fricatives) even with close vowels. This would support the assumption that even if we exclude the function of the lower jaw, the back-root of the tongue in synergism with the sphincter muscles of the pharynx could still provide an efficient articulatory parameter in speeding up the constriction for the pharyngeal fricatives. It is true that the durational differences with close vowels did not show as high values as those with open vowels, still, this could add another element in supporting our hypothesis in the sense that the durational differences were higher with open vowels because of the additional function of the jaw movement and its consequential effect on the movement of the tip, the blade and the palatine dorsum of the tongue in the case of front and central fricatives.

From the perceptual point of view the durational differences between vocoids before back consonants and

and those before front and central consonants hover around the DLs values[1] and are probably of little perceptual and hence little phonological value; they are mainly phonetically significant.

6.4.4 Conclusions

For the particular phonetic contexts of I.S.A. investigated on the myodynamic, aerodynamic and acoustic levels, our conclusions could be summarised as follows:

1. Vocoids are shorter before glottal and pharyngeal contoids than before labio-dental, denti-alveolar, palato-alveolar and uvular contoids.

2. The shorter acoustic duration of vocoids preceding the pharyngeal fricatives than those preceding their corresponding front and central fricatives could be ascribed to the shorter articulatory distance moved by the back-root of the tongue in synergism with the sphincter muscles of the pharynx to execute the constriction for the pharyngeal fricatives. On the other hand, the higher levels of significance of the durational differences of open vowels before pharyngeal versus front and central fricatives could be ascribed to the movement of the lower jaw which has its consequential effect on prolonging the

---

(1) From the data shown in Table 4.5.1 if we pool all the consonant environments of the pharyngeal fricatives (voiced and voiceless) on the one hand, and all the consonant environments of front and central fricatives (voiced and voiceless) on the other hand, we can see that the average durational difference between them is 30 msec.

articulatory distance taken by the tip, the blade and the palatine dorsum of the tongue to accomplish the constriction for front and central fricatives.

3. The durational differences of vocoids before back versus front and central contoids are phonetically significant but have little perceptual and hence little phonological value.

6.5 Stressed Versus Unstressed Syllables

6.5.1 Summing Up of the Acoustic Data

Our acoustic investigation of vowel duration in stressed versus unstressed syllables showed the following results:

1. The acoustic duration of vowels is very significantly longer in stressed than in unstressed syllables in all the following cases:

(a) In two bisyllabic minimal pair words where a shift of stress from the first to the second syllable corresponds to a difference in meaning e.g. /'ʃirbuu/ versus /ʃir'buu/.

(b) In two bisyllabic nearly minimal pair words where a shift of stress from the first to the second syllable is associated with a change in the length of the second syllable (from short to long syllable) as well as in meaning e.g. /'kitab/ versus /ki'taab/.

(c) In bisyllabic versus trisyllabic words and trisyllabic versus four syllable words where the same long syllable undergoes a shift of stress from a secondary to a primary stress and another long syllable is added at the end e.g. /ʕad'daad/ versus /ʕad,daa'daat/.

2. Values of levels of significance for duration difference and/or average durations are much higher for (a) than for (b) and (c) mentioned above.

3. The analysis suggests that vowel duration is a very important acoustic correlate of stress and the role of both vowel duration and Fo outweighs the role of intensity.

6.5.2 <u>Summing Up of the Myodynamic and Aerodynamic Data</u>

Our myodynamic and aerodynamic data showed the following results in the two bisyllabic similar words /'<u>ki</u>tab/ versus /<u>ki'</u>taab/.

1. Stressed syllables are characterized by the following myodynamic and aerodynamic correlates:

(a) A delayed closure time for the syllable-final plosive and a correspondingly longer duration of vocal folds adduction of vocoids.

(b) Higher intra oral pressure for the syllable-initial plosive and lower for syllable-final plosive.

(c) Shorter occlusion duration for the syllable-final plosive.

2. Unstressed syllables are characterized by the following myodynamic and aerodynamic correlates:

(a) An earlier closure time for syllable-final plosives and a correspondingly shorter duration of vocal folds adduction of vocoids.

(b) Lower intra oral pressure for syllable-initial plosive and higher for syllable-final plosive.

(c) Longer occlusion duration for the syllable-final plosive.

6.5.3 Discussion

From our literature review it seems that, from the phonological point of view, most linguists agree on the fact that stress and vowel length are closely related (Trubeżkoy (1969), O'Connor (1973), Ladefoged (1975)). (See Section 1.4.2). In C.A. as well as in I.S.A. we have also noticed the fact that stress and long syllables and hence long vowels are interrelated (Birkland (1954), Mitchell (1960)). (See Sections 1.5.1, 1.5.2 and 1.5.3).

From the acoustic point of view the same trend has also been observed; the acoustic durations of vowels are considerably affected by stress in many languages and they are invariably longer in stressed than in unstressed syllables (Fry (1955, 1958), Tiffany's (1959), Delattre (1966, 1969), Lindblom (1963)). (See Section 2.4.2). It has also been observed that vowel duration is a very important acoustic correlate of stress and could serve as an efficient cue for the perception of stress (Fry, (1955, 1958), Adams & Munro (1978), Morton & Jassem (1965). (See Section 2.4.1). Our acoustic data summarized in section 6.5.1 showed the same acoustic trend and are, therefore, consistent with the acoustic data reported by the above mentioned studies, indicating that the influence of stress on the acoustic duration of vowels is indisputable.

Besides this apparent trend, the data showed interesting findings concerning the contraversial issue of whether stress has a phonemic function in I.S.A. As can be seen from Table 4.6.1 the shift of stress from the first to the second syllable in /'ʃirbuu/ versus /ʃir'buu/ and /'ʃirbii/ versus /ʃir'bii/ (see Section 1.5.3) corresponds to a difference in the meaning of the word as well as a substantial lengthening of the vowel of the second syllable. As can be understood from the syllabic structure and stress patterns of I.S.A. in /ʃir'buu/ and /ʃir'bii/ the final pronominal /h/ is completely dropped and the listener here has to look for other cues to differentiate perceptually between say, /'ʃirbuu/ and /ʃir'buu/ since the final pronominal /h/ of /ʃir'buu/ is rendered phonologically redundant. It seems most likely that the listener here uses the longer acoustic duration of the vowel of the second stressed syllable, among other correlates, as a perceptual cue to perceive it as a stressed syllable and hence distinguishes it from the unstressed syllable which has a relatively shorter vowel.

Ferguson (1957) has tackled this question from the phonological point of view; (see Sections 1.5.1 and 1.5.3) he states that two forms like these differ in having a longer final vowel and in having stress on the last syllable instead of the first. He also states that it is an interesting phonological problem whether to consider this contrast in Damascus Arabic and Iraqi Arabic:

> "... as primarily a length difference or a stress difference or both equally. Each view has evidence to support it and each has competent linguists to favour it." (op. cit., p.476).

The data available in this study strongly suggest that both cases may be true. In the first instance the data suggest that it is certainly a length difference because vowel duration of the second stressed syllables of the words in question are not only statistically very significantly longer than those in unstressed syllables but also their durational averages are almost twice those of the latter syllables with the difference far above the DLs values (see Table 4.8 and Figure 4.15). Still, we cannot rule out considering /ii/ and /uu/ in the syllable when it is unstressed as long vowels because from the grammatical and orthographic as well as the phonological points of view they should be represented as long and not as short vowels.

In the second instance, i.e. whether it is primarily a stress difference, our data strongly suggest that it is definitely the case; as attested by the results shown in the same table, not only duration but all three acoustic correlates of stress have significantly and/or very significantly higher values for stressed than for unstressed syllables.

Ferguson (op. cit.) disagrees with Smeaton (1956) who states that we distinguish between the vowels in question on the basis of "virtual /h/". Ferguson believes that the phonemic contrast between these two is intimately connected with stress because the presumed /h/ of the stressed syllable is completely inaudible and totally insignificant from the phonological point of view.

Our hypothesis largely agrees with that of Ferguson's (op. cit.). We believe that the location of stress on the second syllable is intended by the speaker for phonemic objectives. This results in longer duration of the vowel in the stressed syllable which is used by the listener as a cue for perceiving it as a stressed syllable and hence as phonologically distinctive from the unstressed syllable.

Before we proceed to discuss our myodynamic and aerodynamic results, we would like to point out that we were curious, in so far as the data available in this study are concerned, to know some of the myodynamic and aerodynamic correlates that could serve in the articulatory realization of stress on the one hand, and on the other, to see which of these correlates could be associated with the observed acoustic durational differences of vowels in stressed versus unstressed syllables. Therefore, it is by no means to be understood that we aimed at a comprehensive investigation of the physiological correlates of stress.

From the results shown in Table 5.5, it is interesting to observe that in the case of the shorter duration of vowels in the unstressed syllable /kit/ in /ki'taab/ there is an advanced closure time of the final plosive which is at the same time the initial plosive of the second stressed syllable. This is particularly important here because this intervocalic plosive is characterized by higher intra oral pressure and longer closure duration and preceded by a shorter duration of vocal folds adduction. These values are quite the opposite when the same intervocalic plosive terminates the first stressed syllable and simultaneously begins the second unstressed syllables i.e., in the word /'kitab/. Consequently, the observed acoustic differences of vowels in stressed versus unstressed syllables can be made to correspond to a certain myodynamic programme for the supraglottal articulation. This leaves no alternative but to explain in myodynamic terms the shorter acoustic duration of vowels in the unstressed syllable as being due to the advancedclosure time of the final plosive which, in order to be perceived as belonging to the second stressed syllable, must have a longer closure duration and higher intra oral pressure. This is also true as regards the preceding stressed vowel when the same intervocalic plosive terminates the first stressed syllables and simultaneously begins the second unstressed syllable; the vowel here behaves likewise, i.e., in order to be perceived as belonging to the first stressed syllable it must have a longer duration of vocal folds adduction and consequential delay of closure time for the following plosive and hence a longer acoustic duration to be used by the listener as a cue to perceive the stressed syllable.

Slis (1971) ascribes the advanced closure time as well as the longer closure duration of the stressed consonants to an increase in articulatory effort accompanying the realization of stress. His e.m.g. data showed that greater articulatory effort is accompanied by an advancement in time of articulatory commands and that the closing commands are more affected by articulatory effort than the opening commands and states that this 'originates at a higher level in the speech production chain' (op. cit., p.183). Nooteboom (1972) agrees with Slis (op. cit) that the increase of stressed consonant duration may be a part of a perceptual pattern serving the signalling of syllable stress. He states:

> "The origin of the effect may well lay in some lower-implementation rule, whereas the acoustical results i.e. the increased consonant duration may have taken on the function of signalling syllable stress.' (op. cit., p.60).

In so far as the data available in this study are concerned, it is difficult to find a clear correlation between stress and articulatory effort as this requires the investigation of the muscular activity involved in producing the articulatory realization of stress. It is true that the stressed intervocalic plosive [t] is characterized by higher intra oral pressure and longer closure duration but it remains dubious whether this is part of a lower-implementation rule of articulatory effort as suggested by Slis (op. cit.).

What seems plausible here is that the advanced closure time of the stressed [t] is part of an articulatory timing of the supraglottal articulation gestures probably planned at a higher linguistic level serving in the realization of the second syllable as a stressed syllable and simultaneously contributing to the shortening of the preceding duration of vocal folds adduction and the consequential shorter acoustic duration of the vowel of the first unstressed syllable. This is compatible with

Nooteboom's hypothesis in the sense that the resulting acoustic durations i.e. the shorter duration of the preceding unstressed vowels and the longer duration of the following stressed consonant and vice versa could be part of a perceptual pattern serving in signalling syllable stress.

6.5.4 Conclusions

For the particular phonetic contexts of I.S.A. investigated on the myodynamic, aerodynamic and acoustic levels, our conclusions could be summarized as follows:

1. The acoustic durations of vowels are very significantly longer in stressed than in unstressed syllables indicating the indisputable influence of stress on vowel duration.

2. Vowel duration and fundamental frequency probably play a very important role in the acoustic realization of stress; they outweigh the role of intensity.

3. There is a clear indication that stress could have a phonemic function in words like /'ʃirbuu/ versus /ʃir'buu/ where the postulated final /h/ of the stressed syllable is phonologically redundant. The resulting longer vowel duration of the second stressed syllable is used by the listener, among other acoustic correlates, as a cue for the perceptual realization of stress and not as phonologically distinctive from the shorter vowel duration of the corresponding unstressed syllable.

4. The longer durations of vowels and consonants when they are stressed and their shorter duration when they are unstressed could be related to respective articulatory timings of the supraglottal articulation gestures probably planned at a higher linguistic level. The resulting acoustic durations could be part of a perceptual pattern serving in signalling syllable stress.

6.6 Geminate Versus Non-geminate Consonants

6.6.1 Summing Up of the Acoustic Data

Our acoustic investigation showed that vocoids are very significantly longer before intervocalic non-geminates than before intervocalic geminates no matter whether the geminates/non-geminates are voiced plosive, voiceless plosives, voiceless emphatic plosives or voiceless fricatives, in stressed or unstressed syllables. (For more details see Section 4.3.4).

6.6.2 Summing Up of the Myodynamic and Aerodynamic Data

Our myodynamic and aerodynamic investigation of the minimal pair /fat'taat/ versus /fa'taat/ with intervocalic geminate versus non-geminate showed that the geminates and non-geminates are characterized by the following correlates.

1. Geminate Contoids

(a) Longer duration of myodynamic occlusion.

(b) Higher intra oral pressure.

(c) Advanced closure time and hence shorter T_1.[1]

(d) Shorter duration of vocal folds adduction of the preceding vocoid.

2. Non-geminate Contoids

(a) Shorter duration of myodynamic occlusion.

(b) Lower intra oral pressure.

(c) Delayed closure time and hence longer T_1.

(d) Longer duration of vocal folds adduction of the preceding vocoid.

Our investigation also showed that the first syllable as well as the word overall myodynamic timings are very significantly longer for /fat'taat/ than for /fa'taat/. On the other hand, the acoustic measurements included in the same table showed a very significantly longer acoustic duration of the geminate than that of the non-geminate contoids. They also showed that the first syllable as well as the word overall acoustic timings are very significantly longer for /fat'taat/ than for /fa'taat/. (For more details see Section 5.4.5).

---

(1) See Table 5.6 for the definition of T_1.

6.6.3 Discussion

In our review of the literature on gemination (see Section 2.5.1) we have noticed the fact that a geminate consonant could be articulated as one long consonant (Rousselot (1891), Hegedus (1951)). Other linguists have found that it involves a rearticulation of the same consonant and hence is considered as comprising double consonants, (Sievers (1871), Stetson (1951)). Perceptual tests, on the other hand, confirmed that consonant duration is a major cue for the perception of gemination (Delattre (1971)). In Arabic, a geminate consonant is considered as one long consonant or indissoluble identical clusters (Blanc (1952), Nasr (1960) and Al-Ani (1978)). It has also been found that for some languages a longer consonant is preceded by a shorter vowel and vice versa Slis (1971), Nooteboom & Slis (1972) and Thananjayasingham (1976). (see Section 2.5.2). It has also been observed that a geminate consonant is preceded by a shorter vowel (Rousselot (1901), Delattre (1971)). This is not true. See page 97 of this study.

Josselyn (of course!)

In so far as the data available in this study are concerned, neither from the acoustic nor from the myodynamic and aerodynamic points of view is there any indication that gemination involves a rearticulation of the same consonant. They all show steady and uninterrupted traces for the occlusion time of the geminate plosives. This is compatible with the hypothesis suggested by Blanc, Nasr and Al-Ani (op. cit.) in that a geminate consonant in Arabic is articulated as one long indissoluble consonant.

The main question raised in this section of our study is why vowels are shorter before geminate than before non-geminate consonants. If we go back to Table 5.6 we can see that our data revealed four important facts.

1. The acoustic duration of the preceding vocoids and the following geminate/non-geminate contoids can be related to similar articulatory timings for the durations of the vocal folds adduction for the preceding vocoids and for the myodynamic occlusion of the following geminate/non-geminate contoids.

2. In consequence, the shorter acoustic duration of the preceding vocoid could be ascribed to the advanced closure time of the following geminate contoid.

3. The assumption that the shorter acoustic duration may be compensated for by the duration of the geminate is ruled out by the fact that the overall timings of the first syllable as well as the whole word showed very significant differences, i.e. there is no indication of a temporal compensatory adjustment between the preceding vocoid and the following geminate/non-geminate contoid neither on the syllable nor on the word levels.

4. The acoustic durational differences in geminate versus non-geminate contoids are far beyond the DLs values and are, therefore, perceptually significant and hence

phonologically distinctive. On the other hand, the durational differences of vocoids preceding geminate versus non-geminate contoids hover around the DLs values. They are phonetically significant but probably have little or no phonological significance.

It is also interesting to observe that the longer occlusion duration of the geminate contoid accompanied by a higher intra oral pressure despite the fact that in some cases geminate and the non-geminate are both stressed. This may be indicative of a higher articulatory effort accompanying the act of moving and holding the articulators to maintain a longer occlusion time for the geminate contoid. Catford (1977) believes that the articulation of gemination involves: 'minor diminution and re-establishment of initiator power.' (op. cit., p.210). He also states that: 'the term "geminate" has also been commonly used for the "strong" or "tense" consonants occurring in east Caucasian languages.' (ibid). Again, it is difficult to confirm in this study that the articulation of geminate could be correlated with strong articulatory effort because, to do so, one needs to investigate which muscles are responsible for this "strong" or "tense" articulation.

Nevertheless, it seems plausible to speculate at this stage of our analysis that the advanced closure time of the geminate contoid is part of articulatory timings planned at a higher linguistic level; the speaker deliberately executes an earlier occlusion onset and maintains a longer occlusion time for the geminate for phonological reasons. This can be a part of an implementation rule of an articulatory effort (Slis 1967) which is a consequence of a higher-level linguistic rule. The resulting acoustic durations, i.e. the shorter duration of the preceding vocoid and the longer duration of the following contoid could be part of a perceptual pattern serving in the perceptual realization of gemination as a phonological phenomenon. It seems obvious here that the longer acoustic duration of the consonant is not the only perceptual cue that helps the listener to distinguish geminate from non-geminate consonants. It may be very well considered as a major perceptual cue as found by Delattre (1971) (see Section 2.5.1) but we should not ignore the shorter acoustic duration of the preceding vowel, which, we believe, also contributes to the perceptual realization of the following long consonants as geminate consonants and hence phonologically distinctive from the non-geminate consonants which are acoustically shorter and preceded by a relatively longer vocoid. It is true that the acoustic duration of the geminate is even more than twice of that for the non-geminate and the duration difference is very much beyond the DLs values which might be sufficient for the perceptual requirements to perceive it as a geminate; however, since the geminate consonant investigated here does not involve a rearticulation of the same consonant, the preceding vowel needs to be shortened to enhance the phonological distinction between the longer consonants as geminate and the shorter one as non-geminate.

6.6.4 Conclusions

For these particular phonetic contexts of I.S.A. investigated on the myodynamic, aerodynamic and acoustic levels, our conclusions could be summarized as follows:

1. From the phonetic point of view there is no evidence that an intervocalic geminate involves a rearticulation of the same contoid; it is articulated as one long indissoluble contoid.

2. The shorter acoustic duration† of the vocoid preceding the geminate could be ascribed to the advanced closure time of the geminate contoid.

3. The shorter acoustic duration† of the preceding vowel and the longer acoustic duration of the following geminate result from a similar articulatory programme for the supra-glottal articulation. These acoustic durations could be part of a perceptual pattern serving in the perceptual realization of gemination as a phonological phenomenon.

6.7 Suggestions for Further Research

As we approach the end of this study, we realize that there remains a number of questions which have not been properly answered. A more extensive investigation for further research is, therefore, justified to tackle the following questions:

1. In the case of long versus short vowels a perceptual study of vowel quality is needed in which quality and duration are controlled to see whether the listener responds mainly to one or other of them, or to both concomitantly.

2. In the case of DLs values, a perceptual test is required to see whether the DLs values mentioned in this study are applicable to Iraqi listeners.

3. In the case of vowel duration followed by voiced versus voiceless consonants, a more sophisticated myo-dynamic (glottographic and/or fiberoptic) investigation of the larynx is required to assess the actual glottal contrast (glottal aperture/glottal closure) associated with voiced versus voiceless consonants and its implications on the variations of the preceding vowel duration.

4. A more sophisticated myodynamic (cineradiographic) investigation is required in the case of emphatic versus non-emphatic consonants to assess the prior movement of the tongue before assuming the position for the primary constriction of the emphatic consonants and its implications on the preceding vowel duration.

5. A more sophisticated (e.m.g.) investigation is needed to investigate whether an articulatory effort is involved

in the production of stressed syllables and consonant geminates.

6. A perceptual test is needed to assess our analysis of the acoustic correlates of stress. Duration, Fo and intensity could be controlled in synthetic speech and judgements of stress could be obtained from Iraqi listeners. These judgements could be correlated with variations of the above acoustic parameters.

7. A further investigation is needed to construct rules for the duration of vowels under the combined influences of the various contextual factors investigated in this study, like the rules being developed for English by Klatt (1973) (see Section 2.3.1). That is, to see whether, for instance, a stressed vowel is affected by the voicing of the following consonants as much as, more than or less than when it is unstressed.

APPENDIX 1

The following is a list of all the test words investigated in this study with their English equivalents:

/'baaba/	his door
/'b̲aab̲a/	daddy
/baad/	worn out
/baas/	kissed
/baas̲/	bus
/baat/	spent the night
/baat̲/	armpit
/baaz/	falcon
/baaɣ/	tyrant (rarely never used in I.S.A. usually C.A. pausal)
/baaʕ/	sold
/bad/	way out, escape
/bas/	enough
/bas̲/	peeped
/'baʃar/	human beings
/ baʃʃar/	gave good news.
/ bat /	N. luck. V. decided
/bat̲/	N. ducks. V. poked, pricked
/ba't̲aala/	unemployment
/bat̲'t̲aala/	unemployed, useless (fem. sing.)
/baz/	stinged
/boos/	kissing
/buus/	kiss (imp. sing.)
/daas/	stepped on

/daaɣ/	melted (specially for oil)
/daax/	became dizzy
/dal/	indicated
/das/	insinuated, slipped
/diis/	step on (Southern dialect)
/dis/	insinuate, slip (imp. sing.)
/duus/	step on (imp. sing.)
/dus/	step on (imp. sing. (rarely used in I.S.A. usually C.A.)
/faaf/	nonsense word. Also a trade mark for paper tissues.
/faas/	adze. ax
/faaʃ/	not inflated
/faat/	passed by
/faax/	relaxed, relieved
/faaq/	woke up, became conscious
/faaħ/	spread (specially for perfumes or flowers smell)
/faaʔ/	the letter "f"
/fa'taat/	a girl
/'fatiħ/	opening, conquest
/fat'taat/	person or instrument that breaks up solid things into fragments
/'fattiħ/	cause to open (imp. sing.)
/ki'taab/	a book
/'kitab/	wrote
/raf/	flickered, flapped

/riiʃ/	feathers
/riiħ/	wind
/ruuʃ/	rush about (imp. sing.)
/ruuħ/	go away (imp. sing.)
/<u>r</u>a<u>f</u>/	shelf
/saad/	pervaded
/saas/	foundation
/sad/	dam
/sa'daad/	wisdom
/sad'daad/	person or instrument that closes
/'sitar/	veiled
/si'taar/	veil
/<u>s</u>aad/	the letter /<u>s</u>/
/<u>s</u>aa<u>s</u>/	sauce
/<u>s</u>aaɣ/	moulded, fashioned (specially by a goldsmith)
/<u>s</u>ad/	deflected
/sooɣ/	moulding, fashioning
/<u>s</u>uuɣ/	mould, fashion (imp. sing.)
/'ʃirbii/	drink (imp. fem. sing.)
/ʃir'bii/	drink it (imp. fem. Sing.)
/'ʃirbuu/	drink (imp. plur)
/ʃir'buu/	drink it (imp. plur.)
/taab/	swore off, repented
/tal/	hill
/tuut/	mulberry
/<u>t</u>aab/	recovered, healed

/ṯuuṯ/	horn like sound
/zaad/	food
/ʕaad/	came back
/ʕad/	counted
/'ʕadad/	number
/'ʕaddad/	numbered
/ʕad'daad/	meter
/ʕad,daa'daat/	meters
/ʕid/	count (imp. sing.)
/ʕiid/	feast day, festival
/ʕud/	come back (imp. sing.)
	(rarely used in I.S.A. usually C.A.)
/ʕuud/	come back (imp. sing.)
/ʔistiʕ'daad/	preparation, readiness
/ʔistiʕ,daa'daat/	preparations

APPENDIX 2

M A W U*

Mann-Whitney U-test Program

1. Introduction

The Mann-Whitney U-test is a non-parametric significance test. The program follows the procedure set out in Robson's "Experiment, Design and Statistics in Psychology" (Penguin), pp.106-111. Robson suggests that if one or both sets of scores should exceed 19 in number the test should be carried out as a large-sample case, the result being given as a *z*-score related to the normal distribution. The MAWU program does this for you automatically, so that if one or both of your sets of scores should exceed 19 in number the computer will give you not only U and U' as normal, but also *z*.

As a further refinement, the program counts the number of ties encountered in ranking the scores and where relevant applies the correction for ties suggested in Siegel's "Nonparametric Statistics", pp. 123-126, using his formula 6.9. The computer will give you both corrected and uncorrected results, plus the number of ties encountered.

2. Operation

Load the program in the usual way, then type RUN. The

---

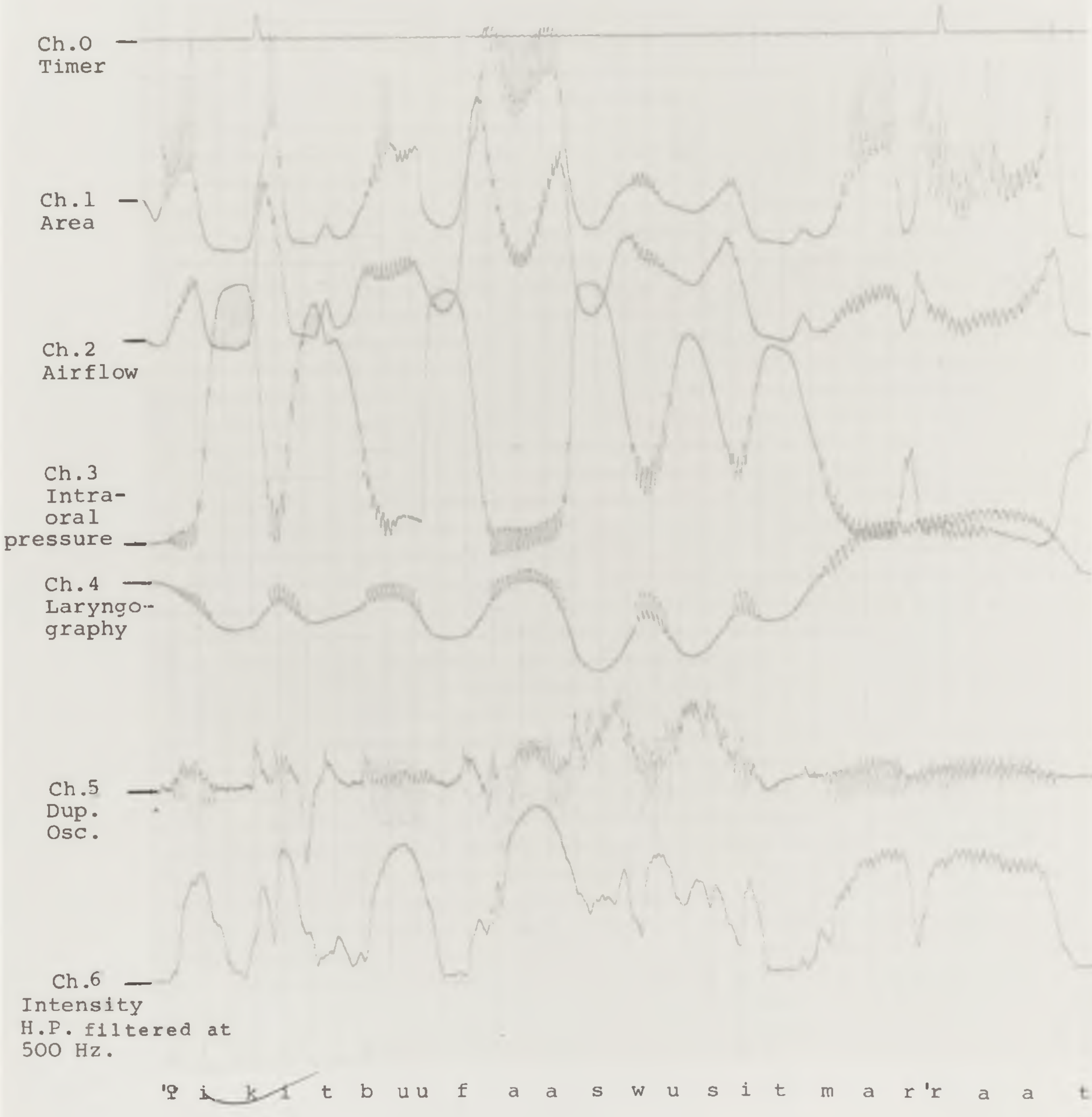
* After Roach (1978b)

computer asks for the first set of scores and indicates that you should put-99 at the end. What this means is that when you have typed in all the scores of one set, in response to the computer's question marks, you should type in one more (-99) as if it belonged to the data. The computer will not add it to the other results, but will take it as a signal to stop requesting data for the current set. It is therefore important to note that if your data may include -99 as a genuine score, the program must be modified to use some other dummy number for terminating input.

When input is finished for the first set, the computer requests input of the second set in the same way. When you type -99 at the end of the second set, the computer calculates the results and displays them. This calculation may take several seconds. The computer then asks if you want the program to repeat for another set of data. You should answer YES or NO.

Some general restrictions: the number of scores in each set may not exceed 100, and any score must be within the range -10,000 to +10,000. These limits can be altered if necessary.

APPENDIX 3



Mingogram of the word /faas/ in the carrier sentence /'ʔikitbuu faas wu sit mar'raat/ showing all the channels displayed for the myodynamic and aerodynamic experiments of Chapter Five. For more details of instrumentation see block diagram of Figure 5.1.

BIBLIOGRAPHY

Abberton, E. (1972). 'Some Laryngographic Data for Korean Stops' in Journal of the International Phonetic Association, Vol. 2, No.2. pp. 67-68.

Abercrombie, D. (1967). 'Elements of General Phonetics'. Edinburgh University Press.

Adams, C. and Munro, R.R. (1978). 'In Search of the Acoustic Correlates of Stress: Fundamental Frequency, Amplitude, and Duration in the Connected Utterance of Some Native and Non-native Speakers of English' in Phonetica, Vol. 35, pp. 125-156.

Al-Ani, S.H. (1970). 'Arabic Phonology' Mouton. The Hague, Paris.

Al-Ani, S.H. and May, D.R. (1978). 'The Phonological Structure of the Syllable in Arabic'. Reprinted in "Readings in Linguistics" Ed. Al-Ani, S.H., Indiana University, Linguistics Club, pp. 113-125.

Ali, L.H. and Daniloff, R.E. (1972). 'A Cinefluorographic-Phonological Investigation of Emphatic Sounds Assimilation in Arabic' in Proceedings of the 7th International Congress of Phonetic Science, Montreal 1971, Mouton 1972, pp. 639-648.

Anis, I. (1971). 'ʕal-ʕswaat-ʕal-luɣawijja' "The Sounds of Language" 4th ed., Cairo: Anglo-Egyptian Bookshop.

Aziz, O. (1976). 'Some Aspects of Kurdish Phonology and Phonetics' (Unpublished) M. Phil. Thesis, Department of Phonetics, University of Leeds.

Belasco, S. (1953). 'The Influence of Force of Articulation of Consonants on Vowel Duration' in JASA, Vol. 25, pp. 1015-1016.

Blanc, H. (1953). 'Studies in North Palestinean Arabic' Jerusalem.

Birkeland, H. (1954). 'Stress Patterns in Arabic' in "Avhandlinger utgitt av Det Norske Videnskaps-Akademi Oslo" 11. Hist-filos. Klasse, No. 3, pp.1-45. Oslo. Jacob Dybwad.

Catford, J.C. (1977). 'Fundamental Problems in Phonetics' Edinburgh University Press.

Charles, T.K. (1947). 'An Introduction to the Phonetics of American English.' The Roland Press Company, New York.

Chen, M. (1970). 'Vowel Duration as Function of the Voicing of the Consonant Environment.' in Phonetica, Vol. 22, pp. 129-159.

Chomsky, N. and Halle, M. (1968). '<u>The Sound Patterns of English</u>.' Harper & Row, Publishers, New York.

Condax, I.D.and Krones, R.R. (1976). 'Duration of Four Vowels in Manually Produced Synthetic Speech.' in <u>Journal of Phonetics</u>, Vol. 4, pp. 255-264.

Delattre, P. (1962). 'Some Factors on Vowel Duration and Their Cross-Linguistic Validity.' in <u>JASA</u>, Vol. 34, pp. 1141-1142.

Delattre, P. (1966). 'A Comparison of Syllable Length Conditioning Among Languages.' in <u>IRAL</u>, Vol.4, pp. 183-198.

Delattre, P. (1969). 'An Acoustic and Articulatory Study of Vowel Reduction in Four Languages.' in <u>IRAL</u>, Vol. 7, pp. 295-325.

Delattre, P. (1971). 'Consonant Gemination in Four Languages: An Acoustic, Perceptual, and Radiographic Study.' in <u>IRAL</u>, Vol. 9, Part 1, pp. 31-52, Part II, pp. 97-113.

Denes, P. (1955). 'Effect of Duration on the Perception of Voicing.' in <u>JASA</u>, Vol. 27, pp. 761-764.

Denes, P. and Penson, E. (1973). '<u>Speech Chain</u>' Anchor Press, New York.

Erwin, W.M. (1963). '<u>A Short Reference Grammar of Iraqi Arabic</u>' George Town University Press, Washington, D.C.

Fant, G. (1958). 'Modern Instruments and Methods for Acoustic Studies of Speech.' in Proceedings of the 8th International Congress of Linguistics, Oslo: University Press, pp. 282-358.

Fant, G. (1960). 'Acoustic Theory of Speech Production' The Hague, Mouton.

Fant, G. (1973). 'Speech Sounds and Features.' The MIT Press.

Ferguson, C.A. (1956). 'Review of Stress Patterns in Arabic by Birkeland' in Language, Vol. 32, pp. 384-387.

Ferguson, C.A. (1957). 'Two Problems in Arabic Phonology.' in Word, Vol. 13, pp. 460-478.

Fischer-Jørgensen, E. (1964). 'Sound Duration and Place of Articulation' in Zeitschrift für Sprachwissenschaft und Kommunikations forschung, Vol. 17, pp. 175-207.

Fischer-Jørgensen, E. (1968). 'Voicing, Tenseness and Aspiration in Stop Consonants with Special Reference to French and Danish.' in Annual Report of the Institute of Phonetics, University of Copenhagen, ARIPUC, Vol. 3, pp. 63-114.

Fletcher, H. (1934). 'Loudness, Pitch and the Timbre of Musical Tones and Their Relation to the Intensity, the Frequency and the Overtone Structure.' in JASA, Vol. 6, pp. 59-69.

Fourcin, A.J. (1974). 'Laryngographic Examination of Vocal Fold Vibration.' in International Symposium on Ventilatory Control System. Ed. Wyke, B., Oxford University Press, pp. 315-326.

Fourcin, A.J. and Norgate, M. (1965). 'Measurement of Transglottal Impedance.' in Progress Report, Phonetic Laboratory, University College of London(UCL). pp. 34-40.

Fourcin, A.J. and West, J.E. (1968). 'Larynx Movement Detector' in Progress Report, Phonetic Laboratory, University College of London (UCL), pp. 41-44.

Fourcin, A.J. and Abberton, E. (1971). 'First Application of a New Laryngograph.' in Med. Biol. Illust., Vol. 21, pp. 172-182.

Fourcin, A.J. and Abberton, E. (1977). 'Laryngograph Studies of Vocal Fold Vibration.' in Phonetica Vol. 34, pp. 307-309.

Frøkjær-Jensen, B. (1967). 'A Photo-electric Glottograph' in Annual Report of the Institute of Phonetics, University of Copenhagen (ARIPUC), No.2, pp. 5-19.

Frøkjær-Jensen, B. and Thorvaldsen, P. (1968). 'Construction of a Fabre Glottograph' in (ARIPUC), Vol. 3, pp. 1-5.

Fry, D.B. (1955). Duration and Intensity as Physical Correlates of Linguistic Stress' in JASA, Vol. 27, pp. 765-768.

Fry, D.B. (1958). 'Experiments in the Perception of Stress.' in Language and Speech, Vol. 1, pp. 127-150.

Fry, D.B. (1964). 'The Dependence of Stress Judgements on Vowel Formant Structure.' in Proceedings of the Fifth International Congress of Phonetic Sciences, pp. 306-311.

Ghalib, G.B.M. (1977). 'The Intonation of Colloquial Iraqi Spoken Arabic.' (unpublished) M. Phil. thesis, Department of Phonetics, University of Leeds.

Gimson, A.C. (1970). 'Introduction to English Pronunciation'. Arnold Publishers, London.

Halle, M. and Stevens, K.N. (1967). 'On the Mechanism of Glottal Vibration for Vowels and Consonants.' in Quarterly Progress Report, MIT, No. 85, pp. 267-271.

Hardcastle, W.J. (1976) 'Physiology of Speech Production.' Academic Press.

Hardy, J.C. (1965). 'Air Flow and Air Pressure Studies.' Proc. Conference: Communicative Problems in Cleft Palate. ASHA Reports, 1, pp. 141-151.

Harrell, R.S. (1957). 'The Phonology of Colloquial Egyptian Arabic.' American Council of Learned Societies, New York.

Henry, F. (1948). 'Discrimination of the Duration of a Sound.' in Journal of Experimental Psychology, Vol.38, pp.734-743.

Hixon, T. (1966). 'Turbulent Noise Sources for Speech.' in Folia Phoniatrica, Vol.18, pp.168-182.

House, A.S. (1961). 'On Vowel Duration in English.' in JASA, Vol.33, pp.1174-1178.

House, A.S. and Fairbanks, G. (1953). 'The Influence of Consonant Environment Upon the Secondary Acoustical Characteristics of Vowels.' in JASA, Vol.25, pp.105-112.

Huggins, A.W.F. (1968). 'The Perception of Timing in Natural Speech 1: Compensation within the Syllable.' in Language and Speech, No.11, Part 1.

International Phonetic Association, The Principles of the, University College of London, 1949.

Isshiki, N. and Ringel, R. (1964). 'Airflow during the Production of Selected Consonants.' Journal of Speech and Hearing Research, Vol.7, pp.233-244.

Jassem, W. (1959). 'The Phonology of Polish Stress.' in Word, Vol.15, pp.252-269.

Jones, D. (1950).'The Phoneme: Its Nature and Use.' Heffer, Cambridge, England.

Jones, D. (1976). 'An Outline of English Phonetics.' Cambridge University Press.

Klatt, D.H. (1967). 'Articulatory Activities and Air Flow during the Production of Fricative Consonants.' in Quarterly Progress Report, MIT. January, Vol. 15, pp. 257-260.

Klatt, D.H. (1973). 'Interaction between Two Factors that Influence Vowel Duration.' in JASA, Vol. 54, pp. 1102-1104.

Klatt, D.H., Stevens, K.N. and Mead, J. (1968). 'Studies of Articulatory Activity and Air Flow During Speech.' in 'Sound Production in Man' (Boyhues, A. Ed.) Annals of New York Academy of Science, Vol. 155, pp.42-55.

Kozhevnikov, U.A. and Chistovich, A. (1967). 'Speech: Articulation and Perception.' U.S. Department of Commerce, Fifth Printing.

Ladefoged, P. (1963). 'Some Physiological Parameters in Speech.' in Language and Speech, Vol. 6, pp.109-119.

Ladefoged, P. (1974). 'Elements of Acoustic Phonetics' The University of Chicago Press, Tenth Edition.

Ladefoged, P. (1975). 'A Course in Phonetics.' Harcourt Brace Jovanovich, Inc.

Laver, J. (1968). 'Phonetics and the Brain.' in Work in Progress, Department of Phonetics and Linguistics, University of Edinburgh, No. 2, pp. 63-75.

Lieberman, P. (1960). 'Some Acoustic Correlates of Word Stress in American English.' in JASA, Vol. 32, pp. 451-454.

Lindblom, B. (1963). 'Spectrographic Study of Vowel Reduction' in JASA, Vol. 35, pp. 1773-1781.

Lindblom, B. (1968). 'Vowel Duration and a Model of Lip Mandible Coordination.' in Quarterly Progress and Status Report, Speech Transmission Laboratory, No. 4, pp. 1-29.

Lisker, L. (1965). 'Supraglottal Air Pressure in the Production of English Stops.' in Haskins Laboratories Status Report on Speech Research, No.SR-4, pp. 3-1 - 3-15.

Lisker, L. (1974). 'On "Explaining" Vowel Duration Variation' in Haskins Laboratories Status Report, No. SR-37-38, pp. 225-232.

Lehiste, I. (1970). 'Suprasegmentals.' The M.I.T. Press.

Lehiste, I. (1971). 'Temporal Organization of Spoken Language' in "Form and Substance" Phonetics and Linguistic Papers presented to Eli Fischer-Jørgensen, pp. 159-169.

Lehiste, I., Morton, K. and Tatham, M.A.A. (1973). 'An Instrumental Study of Consonant Gemination' in Journal of Phonetics, Vol. 1, pp. 131-148.

Mackay, I.R.A. (1977). 'Tenseness in Vowels: an Ultrasonic Study.' in Phonetica, Vol. 34, pp. 325-351.

Malecot, A. (1968). 'The Influence of Articulation of American Stops and Fricatives as a Function of Position' in Phonetica, Vol. 18-19, pp. 95-102.

Malecot, A. (1970). 'The Lenis-Fortis Opposition: Its Physiological Parameters.' in JASA, Vol. 47, pp. 1588-1592.

Mitchell, T.F. (1960). 'Prominence and Syllabication in Arabic.' Bulletin of the School of Oriental Studies, University of London, XXIII, pp. 369-389.

Mitchell, T.F. (1972). 'Colloquial Arabic',Hodder and Stoughton Ltd.

Mortimer, C. (1977). 'A Phonetic Study of Certain Grammatical Distinctions in English: Acoustic and Perceptual Aspects.' (Unpublished) M. Phil. thesis Department of Phonetics, University of Leeds.

Morton, J. and Jassem, W. (1965). 'Acoustic Correlates of Stress.' in Lanugage and Speech, Vol. 8, pp. 159-181.

Naeser, M.A. (1970). 'Criteria for the segmentation of Vowels on Duplex Oscillograms.' Technical Report No. 124. Wisconsin Research and Development Centre for Cognitive Learning. The University of Wisconsin.

Nasr , R.T. (1959). 'The Predictability of Stress in Lebanese Arabic.' Phonetica, Vol. 4, pp.89-94.

Nasr , R.T. (1960). 'Phonemic Length in Lebanese Arabic in Phonetica, Vol. 5, pp. 209-211.

Nooteboom, S.G. (1972). 'Production and Perception of Vowel Duration. A Study of Durational Properties of Vowels in Dutch. Utrecht.

Nooteboom, S.G. and Slis, I.H. (1972). 'The Phonetic Feature of Vowel Length in Dutch.' in Language and Speech, Vol. 15, pp. 301-316.

Nyquist, A. (1961). 'Stress, Intonation, Accent, Prominence in Disyllabic-stress Compounds in Educated Southern English.' in The Proceedings of the 4th International Congress of Phonetic Sciences, Helsinki, pp. 710-713.

Odisho, E.Y. (1973). 'The Role of the Rear Section of the Vocal Tract in Baghdadi Arabic.' (Unpublished) M.Phil. thesis, Department of Phonetics, University of Leeds.

Odisho, E.Y. (1975). 'The Phonology and Phonetics of the Neo-Aramaic as Spoken by the Assyrian in Iraq.' Unpublished Ph.D. thesis, Department of Phonetics, University of Leeds.

O'Connor, J.D. (1973). 'Phonetics'. Penguin Books, London.

Öhman, S.E.G. (1968). 'Peripheral Motor Commands in Bilabial Articulation.' Speech Transmission Laboratory, Quarterley Progress and Status Report, No.4, pp. 30-63.

Peterson, G.E. (1955). 'An Oral Communication Model' in Language, Vol. 31, pp. 414-427.

Peterson, G.E. and Lehiste, I. (1960). 'Duration of Syllabic Nuclei in English.' in JASA, Vol. 32, pp. 693-703.

Peterson, G.E. and Lehiste, I. (1961). 'Some Consideration in the Analysis of Intonation' in JASA, Vol. 33, pp. 419-425.

Raphael, L.J. (1972). 'Preceding Vowel Duration as a Cue of Word-final Consonants in American English.' in JASA, Vol. 51, pp. 1296-1303.

Raphael, L.H. (1975). 'The Physiological Control of Durational Differences Between Vowels Preceding Voiced and Voiceless Consonants in English.' in Journal of Phonetics, Vol. 3, pp. 25-33.

Roach, P.J., (1978a). 'An Experimental Study of Some Articulatory Characteristics of Glottolized English Consonants.' (Unpublished). Ph.D. Thesis., Department of Linguistic Science, University of Reading.

Roach, P.J., (1978b). MAWU, Mann-Whitney U-test, Computer Programme, Departmental Pamphlet, Department of Linguistics and Phonetics, University of Leeds.

Ruhm, H.B., Mencke, E.O., Milburn, B., Cooper, W.A.Jr., and Rose, D.E. (1966). 'Differential Sensitivity to Duration of Acoustic Signals.' in Journal of Speech and Hearing Research, Vol. 9, pp.371-384.

Sacia, C.F. (1926). 'Speech Power and Energy.' in The Bell System Technical Journal, Vol. IV, No.4, 1926, pp. 629-703.

Sacia, C.F. and Beck, C.F. (1926). 'The Power of Fundamental Speech Sounds.' in The Bell System Technical Journal, Vol. 4, No.5, pp. 393-403.

Siegel, S. (1956). 'Nonparametric Statistics for the Behavioural Sciences.' International Student Edition, McGraw-Hill, Kogakusa, Ltd.

Sharf, J.N. (1962). 'Duration of Post-Stress Intervocalic Stops and Preceding Vowels.' in Language and Speech Vol. 5, pp. 26-30.

Scully, C. (1969). 'Problems in the Interpretation of Pressure and Air Flow Data in Speech.' in Phonetics Department Reports, University of Leeds, No.2, pp. 53-92.

Scully, C. (1970). 'Aerodynamic and Acoustic Measures of Time.' University of Essex, Language Centre, Occasional Papers, 9, pp. 14-36.

Scully, C. (1971). 'A Comparison of /s/ and /z/ for an English Speaker.' in Language and Speech, Vol. 14, Part 2, pp. 187-200.

Scully, C. (1973). 'Physical and Perceptual Properties of Speech Sounds.' Departmental Handout, Department of Phonetics, University of Leeds.

Scully, C. (1974). 'A Synthesizer Study of Aerodynamic Factors in Speech Segment Duration.' in Proceedings of Speech Communication Seminar, Stockholm (Fant, G., Ed.), Vol. 2, pp. 227-237.

Scully, C. (1975). 'Transitions of the Vocal Tract for Voiced and Voiceless Fricatives' Paper delivered at the 8th International Congress of Phonetics Sciences, Leeds.

Scully, C. (1979). 'Model Prediction and Real Speech: Fricative Dynamics.' in "Frontiers of Speech Communication Research." Editors Lindblom, B. and Ohman, S. Academic Press, London, pp. 35-48.

Slis, I.H. (1967). 'What Causes the Voiced-Voiceless Distinction?' in IPO Annual Progress Report, No.2, pp. 71-80.

Slis, I.H. (1968). 'Experiment on Consonant Duration Related to the Time Structure of Isolated Words.' in IPO Annual Progress Report No.3, pp. 71-80.

Slis, I.H. (1970). 'Articulatory Measurements on Voiced, Voiceless and Nasal Consonants.' in Phonetica Vol. 21, pp. 193-210.

Slis, I.H. (1971). 'Articulatory Effort and Its Durational and Electromygraphic Correlates.' in Phonetica, Vol. 23, pp. 171-188.

Slis, I.H. and Cohen, A. (1969). 'On the Complex Regulating the Voiced-Voiceless Distinction.' Parts I and II in Language and Speech, Vol. 12, pp. 80-102, 137-155.

Smeaton, B.H. (1956) 'Some Problems in the Description of Arabic.' in Word, Vol. 12, pp. 357-68.

Small, A.M. and Campbell, R.A. (1972). 'Temporal Differential Sensitivity for Auditory Stimuli.' in American Journal of Psychology, Vol. 75, pp. 401-410.

Stetson, R.H. (1951). 'Motor Phonetics' (Second Edition), Amsterdam: North Holland Publishing Co.

Stott, L.H. (1935). 'Time-Order Error in the Discrimination of Short Tonal Durations' in Journal of Experimental Psychology, Vol. 18, pp. 741-766.

Thananjayarajansingam, S. (1976). 'Duration of Inter-vocalic Stops in Ceylon Tamil' in Language and Speech Vol. 19, Part II, pp. 150-159.

Tiffany, W.R. (1959). 'Non-random Sources of Variation in Vowel Quality.' in Journal of Speech and Hearing Research, Vol. 2, pp. 305-317.

Trubetzkoy, N.S. (1969). 'Principles of Phonology.' The Centre for Research in Languages and Linguistics, University of California, Los Angeles.

Van den Berg, J. (1958). 'Myoelastic-aerodynamic Theory of Voice Production.' in Journal of Speech and Hearing Research, Vol. 1, pp. 227-244.

Van den Berg, J., Zantema, J.T. and Doornenbal, P. (1957). 'On the Air Resistance and the Bernoulli Effect of the Human Larynx.' in JASA, Vol. 29, pp. 626-631.

Warren, D.W. and DuBois, A.B. (1964). 'A Pressure-flow Technique for Measuring Velopharyngeal Orifice Area during Continuous Speech.' in Cleft Palate Journal Vol. 1, pp. 52-71.

Zimmerman, S.A. and Sapon, S.M. (1958). 'Note on Vowel Duration Seen Cross-linguistically.' in JASA, Vol. 30, pp. 152-53.

Dictionaries:

Hartman, R.R.K. and Stork, F.C. (1972). 'Dictionary of Language and Linguistics', Applied Science Publishers Ltd., London.

Woodhead, D.R. and Been, W. (Eds.) (1967). '<u>A Dictionary of Iraqi Arabic, Arabic-English</u>.' Georgetown University Press, Washington, D.C.