ACOUSTIC PARAMETERS OF EMPHASIS IN LIBYAN ARABIC

BY

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Abstract

This study investigates the acoustic implementation of the emphatic consonants in Libyan Arabic (LA) as compared to their non-emphatic counterparts. One aim is to explore how the acoustic patterns in LA compare with those found in other Arabic dialects, especially since this is the first study of its kind in LA. Another aim is to relate these acoustic patterns to the articulation of the emphatics.

The acoustic cues that were investigated included the first three formant frequencies in the vowels following plain and emphatic consonants, locus equations, and various vocalic and consonantal duration measurements that have shown to be relevant for the contrast in other varieties of Arabic. Twenty native speakers of LA were recruited for this study and produced randomised target monosyllabic words with initial plain /t d s/ and emphatic /tˤ dˤ sˤ/ in carrier sentences. These consonants were followed by the LA vowels /iː eː ɪ æːɛ oː uː ʊ/.

In terms of formant frequency results, emphasis led to an increase in F1 and F3 and a decrease in F2; this effect was consistent across all vocalic contexts apart from an F3 decrease for /iː/. The effect of emphasis on formant frequency patterns was more pronounced at the onset of vowels than at their midpoint, particularly for the first two formant frequencies. The magnitude of this effect also depended on vowel quality and quantity. These observations were supported by an auditory analysis of the vowels, which were affected by the backing gesture of emphasis.

Locus equations were measured to explore CV coarticulation for both plain and emphatic consonants by the regression analysis of F2 onset and F2 midpoint. In general, the emphatic consonants displayed a lower (flatter) slope and y-intercept than

their plain counterparts, suggesting a low F2 onset and C-to-V coarticulatory resistance.

In terms of durational measurements, the emphatic /tˤ/ was found to have shorter VOT than the plain [t^h] which was aspirated. This showed an effect of the pharyngeal constriction on the timing of laryngeal activities and the degree of glottal opening. On the other hand, closure duration and vowel duration were longer for the /tˤ/ than for the /t/ context. Although this seemed to indicate an effect of emphasis, the total duration of CD, VOT and VD was found to be similar for both the plain and emphatic context, suggesting a temporal relationship between these acoustic parameters. This relationship was also found in the fricative context. The intensity and duration difference between /sˤ/ and /s/ were not significant.

This study has revealed how the acoustic patterns represented the articulation of the emphatic consonants in LA by assessing the contribution of a combination of acoustic features to the plain-emphatic distinction. The cross-dialectal comparison between LA and other Arabic dialects showed that the acoustic results may suggest that the articulatory correlates of emphasis could vary cross-dialectally.

Declaration

I certify that all the material submitted in this work which is not my own work has been identified and that no material is included which has been submitted for any other award or qualification.

Signed:

Hussin Abdulrazaq Kriba

Date: 15th December 2009.

Dedication

This work is dedicated to my much-loved family members, including the memory of my late father, my adored mother and my wife and children.

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I would like first of all to express my thanks to the Almighty Allah for providing me with health, power, patience and determination throughout the period of writing this thesis and for all his countless blessings. I must also direct my thanks to all those who have played an important role for the success of this academic work. There is no possible way that I could show my gratitude to my family, particularly my parents. I am sure that my late father, Mr. Abdulrazaq Kriba would have been very proud of me. I ask the Almighty Allah to bestow His mercy on him. His encouragement and support were one of the main reasons behind my interest in pursuing my higher education. Words can not be enough to thank my mother. May Allah prolong her life and grant her the best health and peace of mind. She has had to endure my long years of absence in silence. I am also thankful to my wife and sons, Abdulrazaq, Abdulmuiz and Abduljabaar. My gratitude is also expressed to my brothers, sisters, relatives and sincere friends who have been very supportive.

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Abbreviations

Algerian Arabic: AA

C: Consonant

CA: Classical Arabic

CD: Closure duration

CEA: Cairene Arabic

DAA: Damascene Arabic

DLA: Derna Libyan Arabic

E: Emphatic consonant

EA: Egyptian Arabic

FD: Fricative duration

FI: Fricative intensity

GA: Gulf Arabic

IA: Iraqi Arabic

Imp: Imperative

JA: Jordanian Arabic

KA: Kuwaiti Arabic

LE: Locus equation

LA: Libyan Arabic

LEA: Lebanese Arabic

MA: Moroccan Arabic

MAA: Mauritanian Arabic

MEA: Meccan Arabic

MSA: Modern Standard Arabic

N: Noun

P: Plain consonant

Pro: Pronoun

QA: Qatari Arabic

RLA: Ryani Libyan Arabic

SLA: Sabha Libyan Arabic

SUA: Sudanese Arabic

SYA: Syrian Arabic

TLA: Tripoli Libyan Arabic

TUA: Tunisian Arabic

YA: Yemeni Arabic

ZLA: Zliten Libyan Arabic

V: Vowel, Verb (depending on context)

VD: Vowel duration

VOT: Voice onset time

CHAPTER I

INTRODUCTION

1.1. Area and topic

The special characteristics of the Arabic emphatic consonants have given an incentive to many western and Arab researchers to explore their phonetic features. The emphatic consonants are highly important from a phonological point of view since they have a distinctive function in the phonemic system of Modern and Arabic dialects. This phonemic function is particularly evident when the emphatic consonants are compared to their plain counterparts from which they are distinguished by an additional secondary articulation represented by tongue back and/or root retraction towards the back wall of the pharynx. While in most Arabic dialects the articulatory, acoustic and/or perceptual features of the emphatic consonants have been explored, these have not been fully investigated for Libyan Arabic (LA). The only study that focuses on the emphatic consonants in LA is the one carried out by Laradi (1983) and which is physiological and articulatory in nature. Acoustic and perceptual studies are rare not only with regards to the examination of emphatic consonants in LA, but also with regards to any of the dialect's other phonetic characteristics. To the best of the researcher's knowledge, there is only one recent acoustic and perceptual study, which focuses on LA vowels (Ahmed 2008) and an MA study which is restricted to one speaker and a number of acoustic parameters of emphasis in LA by the author of this thesis (Kriba 2004). It should also be noted that Ghazali (1977) includes two Libyan speakers among his twelve subjects who represent different Arabic dialects in his spectrographic analysis of emphasis. All this has encouraged the present researcher to fill the gap in the phonetic study of LA by carrying out an investigation of the effect of emphasis on a number of acoustic parameters.

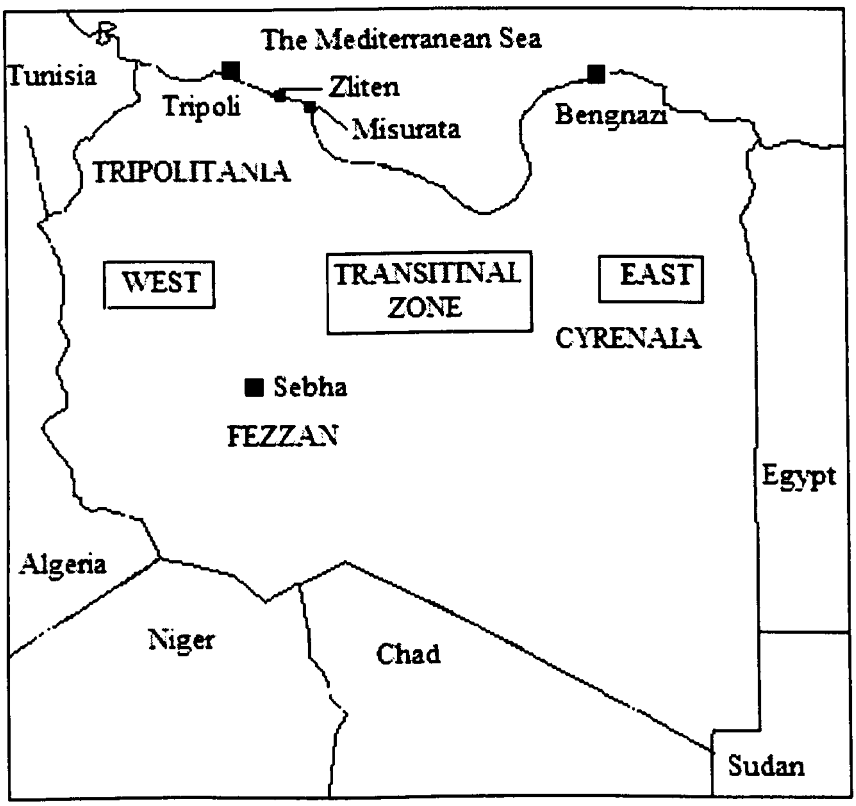
This study focuses only on the coronal emphatic consonants. The uvulars and pharyngeals are not included in this study since they are reported to have a limited effect on the adjacent sounds if compared to the coronal emphatics (Ghazali 1977). Furthermore, the emphaticness of the uvulars and pharyngeals is disputed (see chapter two, section 2.3.2.4). Coronal emphatics are the best consonants to carry the feature emphasis (El-Dalee 1984). As the emphatic consonants have non-emphatic counterparts and are distinguished from them by having an additional secondary articulation, there is a good opportunity to compare the two classes and observe the effect of emphasis, particularly if taking into consideration that most researchers attributed the feature emphasis to the secondary articulation (e.g., Ghazali 1977; Giannini and Pettorino 1982).

The emphatic consonants are distinguished from their plain counterparts by exhibiting a range of identifiable acoustic features due to the presence of the secondary articulation which, according to Laradi (1983), is pharyngealisation in LA. It is therefore hypothesised that the range of acoustic features examined in this study will point towards emphasis in LA suggesting pharyngealisation as a secondary articulation. In order to test this hypothesis, a number of acoustic parameters that are found to provide information about emphasis and its realisation are investigated. Justifications for investigating these parameters are discussed in this chapter, section 1.3 and the methodology chapter, section 3.6.

The current study is concerned with the Zliten variety of Libyan Arabic. The Zliten dialect belongs to the Tripolitania dialectal region in the western part of Libya (see chapter 3, section 3.1 for more details about this dialect). Libya is classified into three main dialectal areas (Pereira 2008). These areas include:

1. western area (Tripolitania and Fezzan)
2. eastern area (Cyrenaia)
3. Transitional area (this extends from the western city of Misurata in the Tripolitania region and the city of Sebha in south to Cyrenaica) (see Figure 1.1).

Fig. 1.1 The three main dialectal areas on the Libyan map[1]



[1] http://geography.about.com/library/blank/blxlibya.htm [Accessed on 08.05.2009].

In this study, a dot underneath the symbol for the plain context is used to refer to emphasis, particularly when the realisation of the secondary articulation is not specified by some researchers. This procedure is adopted by many studies and has become a common practice in the literature on Arabic emphatics (e.g., Lehn 1963; Card 1983; Hussain 1985; Younes 1993, 1994)

1.2. Focus and aim of the study

This study aims to investigate acoustic features that characterise the plain and emphatic consonants in the Zliten variety of LA. This involves relating the acoustic results to the articulation of the emphatic consonants. Comparison between the acoustic results from this study with those from other Arabic dialects is made to find out whether the LA emphatic consonants share the same acoustic features reported for other Arabic dialects.

1.3. Research questions and significance of the study

The main research questions that this study seeks to answer are: (1) which acoustic parameters distinguish the emphatic consonants from their plain counterparts in LA (2) what do these parameters reveal about the articulatory and phonological properties of this variety? The sub-questions that will feed into the main research questions are:

1. What is the effect of emphasis on the formant frequencies of the following vowel?
2. To what extent can locus equation parameters characterise CV coarticulation for the emphatic consonants?

3. Can durational and/or intensity cues in the consonant and the adjacent vowel distinguish the emphatic from the plain consonant?

4. How does the phonetic implementation of emphasis in LA differ from the patterns found in other Arabic dialects and what are the implications for LA phonology?

The current study is the first attempt towards providing a comprehensive acoustic account of the emphatic consonants in LA. This study will look at a combination of acoustic features which have only been examined separately before (e.g., Al-Ani and El-Dalee 1983; Card 1983; Yeou 1997; Al-Halees 2003; Jongman et al 2007). This is to assess the contribution of these parameters to the plain-emphatic distinction.

Another feature of the current study lies in its use of a large number of native LA speakers in order to achieve a better sample representation of the dialect investigated and examine a relatively large database compared to case studies and small numbers before. A survey of the literature has shown that results from some Arabic dialects are based on one or two speakers; in some cases, the author is the only subject of the study (e. g., Al-Nuzaili 1993; Bukshaisha 1985; among others).

This study also allows for an opportunity to compare the acoustic characteristics of the LA emphatics with those of the emphatics in other Arabic dialects. Taking into account that the acoustic output of the emphatics is shaped by their articulation, results from this study can get us a step closer towards understanding the articulatory nature of emphatics in LA. The special articulation of the emphatic consonants is manifest in the formant frequency patterns of adjacent vowels. Formant frequencies are sensitive to the backing gesture of emphasis and the location of the secondary articulation. Therefore, formant frequency results can reflect the articulatory representation of the emphatics in LA and complement results from articulatory studies on LA in particular and other Arabic dialects in general.

Acoustic analysis in this study is combined with auditory analysis in order to explore the quality of vowel allophones in the plain and emphatic contexts and the correspondence between the acoustic and auditory levels of speech processing. Auditory analysis seems to be neglected in most studies on emphasis (e.g., Hussain 1985; Bukshaisha 1985; Norlin 1987; Giannini and Pettorino 1982; Yeou 1997, 2001; Bin-Muqbil 2006; Jongman et al 2007; among others). Some studies list the phonemic realisation of the vowels without discussing its quality in either context while others base their allophonic classification on impressionistic views or general expectations of the allophonic realisation of the target vowels, often based on results from other phonological and acoustic studies. This study attempts to more accurately identify the allophonic quality of vowels through an auditory analysis of all tokens.

The study uses locus equation parameters to infer CV coarticulation for both the plain and emphatic consonants with a focus on the effect of speaker variability and consonantal type on coarticulation. In fact, there are a number of factors that affect coarticulation, e.g., the language (Bladon and Al-Bamerni 1976), prosodic constraints such as word stress (Farnetani 1990), vowel quality (Fant 1973), vowel duration (Lindblom 1963b), the direction of the coarticulatory effect (Recasens et al 1997), and speaking style (Krull 1989). The second formant frequency is used to encode CV coarticulation through a regression analysis of F2 onset and F2 midpoint. As a result of having a secondary articulation, the emphatics are expected to resist coarticulation with the following vowel as compared to their plain counterparts. Locus equation results are discussed in light of the relevant theories and models that account for coarticulation resistance. In fact, locus equation parameters offer an objective and efficient way of encoding CV coarticulation. The traditional approach of only measuring F2 could show the effect of emphasis on F2, but may not reveal the extent to which this could affect CV coarticulation in a way that allows for a cross-dialectal comparison.

This study further investigates the effect of emphasis on durational parameters such as closure duration and VOT in stops, the duration of vowels adjacent to emphatic consonants and fricative duration. VOT investigation is expected to provide information about the effect of emphasis on the timing of voicing and how this timing is controlled by physiological factors related, for instance, to the degree of glottal opening as a function of the pharyngeal constriction of the emphatics. The effect of emphasis on closure duration, on the other hand, is examined in order to look for signs of temporary compensation between closure duration and other acoustic parameters like VOT and vowel duration. This can show whether changes in closure and vowel duration are caused by emphasis or they are related to a temporary relation between acoustic parameters. The effect of emphasis on the duration and intensity of the fricative consonant is examined. This is to assess the claim in the literature concerning the treatment of the emphatic segments as having tenser and longer articulations than their plain counterparts (e.g., Ali and Daniloff 1972a; Bukshaisha 1985). This allows for an opportunity to find out how LA compares with other dialects regarding the durational as well as the non-durational aspects of emphatic realisation. The acoustic results are discussed in light of the accessible theories that account for the articulatory characteristics of emphasis.

The findings of this study may be of relevance to those who intend to proceed with examining the unexplored acoustic features of LA phonetics. Moreover, these findings may be used for cross-dialectal or cross-linguistic comparisons. Although the main focus of this study is comparison between plain and emphatic consonants, it adds another important dimension to the acoustic studies of LA on the grounds that a description of some acoustic features like voice onset time, closure duration, consonant duration and locus equation parameters are not described for LA in general. As a result, the investigation of these parameters can be extended to other segments. Furthermore, understanding the acoustic features of the emphatic consonants in LA could also pave the way for more work on emphasis with respect to, for instance, sex and gender differences in addition to more acoustic, articulatory and perceptual work that this study has not covered.

1.4. Organisation of the study

This thesis is organised into two parts. Part one has two chapters. Chapter One is an introductory chapter that outlines the focus and importance of the topic, the research questions and organisation of this thesis. Chapter Two is dedicated to reviewing the literature related to the topic in question.

Part two is divided into five main chapters. It presents the main experimental work conducted in this study and its chapters follow the sequential order started in part 1. Chapter Three is concerned with an account of the methodology. It focuses mainly on describing the procedures adopted in collecting the data and in taking the acoustic measurements. Chapters Four, Five and Six encompass the results for the acoustic parameters under investigation. Each chapter is assigned to particular parameters. Chapter Four deals with formant frequency results, Chapter Five with locus equation results and Chapter Six with durational and intensity results. Chapter Seven is dedicated to the discussion of the results reported in chapters four, five and six and presents the limitations of the study and suggestions for further investigations.

CHAPTER II

THE EMPHATIC SOUNDS IN ARABIC

2.0. Introduction

This chapter is basically concerned with defining emphasis and the classification of the emphatics in different Arabic dialects. There is also an examination of the phonetic features that distinguish emphatic from non-emphatic consonants. The aim is to explore the nature of the emphatic consonants at different phonetic levels, namely the articulatory, acoustic, and perceptual levels. This survey sheds some light on coarticulatory patterns concerning the spread of the emphatic gesture and the role of locus equation parameters in encoding CV coarticulation for the plain-emphatic distinction. It also focuses on how the production of emphasis is affected by other variables such as age and gender differences in addition to the acquisition of the emphatics. This chapter starts with an overview of Libyan Arabic as compared to other Arabic dialects and varieties. This is to achieve a better understanding of the position of this dialect among other dialects, particularly with respect to its nature and classification.

2.1. Libyan Arabic

The varieties that the Arab speakers use for communicative purposes are generally referred to as Classical Arabic, Modern Arabic and Colloquial Arabic (Haywood and Nahmad 1965). Classical Arabic is the language of Qur'an and well-known writers and poets in the pre-Islamic and Islamic periods. Modern standard Arabic is a simplified and modified form of classical Arabic and nowadays MSA is used by educated people and in the media in Arab countries (Mitchell 1962; Gadalla 2000). Modern standard Arabic is therefore uniform in all Arab countries and represents the formal language in these countries.

Colloquial Arabic refers to the Arabic dialects used for everyday communication in the Arab countries; these dialects differ from one another in terms of their lexical and phonological aspects (Mansouri 2000). The degree of these differences depends on the geographical region; the closer the two dialectal areas are, the more similar their varieties will be and vice versa. The Arabic dialects may also differ from one country to another and/or from one city to another (Mitchell 1962; Mansouri 2000).

The Arabic dialects are basically classified into two main dialectal areas the eastern dialects and the western (Maghreb) dialects (Versteegh 1997; Watson 2002). According to Watson (2002), the dividing line between the western and eastern dialects is Salum, a town in the Libyan-Egyptian border. Thus the eastern dialects include the dialects spoken in Egypt, the Gulf area, Lebanon, Syria, Jordan Iraq and Palestine, and the Maghreb dialects are those spoken in Libya, Mauritania, Morocco, Algeria and Tunisia.

The Maghreb dialects date back to the stages of Hilaali and pre-Hilaali dialects (Versteegh 1997). The pre-Hilaali dialects are regarded as sedentary and grouped into eastern and western dialects. The eastern dialects which are used in Libya, Tunisia, and the east of Algeria kept their three short vowels, while the western pre-Hilaali dialects are used in the west of Algeria and Morocco and are characterised by two short vowels.

There are some phonetic differences between the western and eastern dialects of Arabic. For instance, the western Arabic dialects, unlike the eastern dialects of Arabic, experienced the loss of many short vowels and reduction of long vowels due to the effect of Berber, but this change is rare in Libya (Kaye and Rosenhouse 1997). This shows that Libyan could exhibit some phonetic features that are similar to those of the eastern dialects. Libyan Arabic can be regarded as a dialect connecting the eastern part of the Arab world to its western part particularly if considering the location of Libya in the heart of the Arab world and the Libyan border with Egypt is the dividing line between the eastern and western dialects. According to the experience of the researcher of this study as a native speaker of Libyan Arabic, the dialects spoken in the west of Libya exhibit some similarities with those spoken in the eastern part of Tunisia while the eastern Libyan dialects are similar to those used in the west of Egypt. This shows the role of the geographical region in the dialectal variation as discussed earlier in this section. Every Arab country can be characterised by a number of dialects which may differ from one another and from dialects spoken in other countries.

Furthermore, Kaye and Rosenhouse (1997) indicate that the western dialects are characterised by the loss of the phonological distinction between /s/ and /ṣ/ as well as /z/ and /ẓ/. However, some researchers refer to the presence of the phonemic distinction between /s/ and /ṣ/ in western Arabic dialects such as Tunisian Arabic (Ghazali 1977), Libya Arabic (Laradi 1983; Abumdas 1985) and Moroccan Arabic (Embarki et al 2007).

There are differences between Arabic dialects at the lexical level (Kaye and Rosenhouse 1997). These differences are important since they lead to difficulty in communication between speakers of different dialects unless the speakers are aware of the meanings of the words used in these dialects. Some lexical differences between Arabic dialects show that Libyan Arabic could be more similar to eastern dialects than to western dialects (see shaded words in Table 2.1, columns 1 and 2). The exception is in column 2 where the lexical items in Libyan Arabic (LA) and Mauritanian Arabic (MAA) are similar. There are also some example words in which Libyan Arabic lexical items are completely different from those used in the other western dialects and eastern dialects (see shaded boxes in Table 2.1, columns 3 and 4. This shows that Libyan Arabic could have its own lexical items. Similar words are also used in the western dialects of Algerian Arabic (AA) and Mauritanian Arabic (MAA) to those of the eastern dialects of Cairene Arabic (CAA), Lebanese Arabic (LEA), Iraqi Arabic (IA) and Meccan Arabic (MEA) as shown in column (3). The words used in Damascene Arabic (DAA) are the same as those used in Lebanese Arabic (see Table 2.1). This is indicative of the role of the geography as discussed earlier in this section; both Syria and Lebanon are neighbouring countries.

Table 2.1. Lexical variation across some Arabic dialects (Kaye and Rosenhouse 1997)

		(1) there is not	(2) how much	(3) eggs	(4) very
Western Arabic dialects	LA	/mafi:ʃ/	/kam/	/deħi/	/ja:ser/
	TUA	/mafam:aʃ/	/qad:a:ʃ/	/ʕḍ a:m/	/barʃa/
	AA	/maka:nʃ/	/gad:a:ʃ/	/bi:ḍ/	/bez:a:f/
	MA	/makanʃ/	/(a)ʃħal/	/awladʒa:ʒ/	/bez:af/
	MAA	/maxalagʃi/	/kam:/	/be:ẓ /	/ħat:a/
eastern Arabic dialects	CAA	/mafi:ʃ/	/kam/	/be:ḍ/	/kiti:r/
	LEA	/ma:fi:/	/ʕad:e:ʃ/, /kam/	/be:ḍ/	/kti:r/
	DAA	/ma:fi:/	/ʕad:e:ʃ/	/be:ḍ/	/kti:r/
	IA	/ma:ku/	/jam/	/be:ð̣ /	/kul:iʃ/
	MEA	/ma:fi:ʃ/	/kam/	/be:ḍ/	/kati:r/

A distinction is also made between Bedouin and urban dialects of Arabic; Bedouin dialects are conservative and similar while urban dialects are developed and vary depending on factors like age, gender and social class (Watson 2002). The Bedouin dialects are mainly spoken in the Arabian Peninsula, which is the original home of the Arab tribes (Versteegh 1997). Other dialects spoken outside the peninsula tend to be less conservative. Yet, Versteegh (1997) states that the Bedouin dialects are used in other Arab countries like Libya and Tunisia, Morocco and Algeria, and urban cities are also influenced by the Bedouin dialects.

The Bedouin dialects are thought to have features related to classical Arabic. For instance, the classical Arabic /ɢ/ and /ð/ are used in many Bedouin dialects (Versteegh 1997; Kaye and Rosenhouse 1997). The classical Arabic /ɢ/ remains in use in some Arabic dialects, e.g., Tunisia, Syria, Lebanon, Yemen, Algeria and Morocco, but as a voiceless uvular stop. In some dialects /q/ can also be realised as a glottal stop (e.g., Egyptian, Syrian and Lebanon) whereas in Libyan Arabic, /q/ is realised as[g] (Kaye and Rosenhouse 1997). Some dialects spoken in Libya use the inter-dental sound /ð/ particularly in the eastern part of Libya (Owens 1984). These dialects are thought to be Bedouin as they exhibit features of classical Arabic. It is clear that researchers classify a dialect as a Bedouin if it displays elements of Classical Arabic. However, this may not indicate that a dialect is entirely Bedouin. In Libya, for instance, if speakers of a dialect use /ð/, this is not always a sign of a Bedouin dialect, but it could suggest that the dialect may have a Bedouin origin.

Another difference between urban and Bedouin dialects lies in the fact that the same word may have a certain meaning in a Bedouin dialect and a different meaning in an urban dialect, e.g., /daħraʒ/ means (see) in Galilean Bedouin and (roll something) in urban Palestinian dialects (Kaye and Rosenhouse 1997). Furthermore, many classical Arabic lexical words are found in Galilean Bedouin, but not in urban dialects, e.g., /ħus:a:m/ (sword) /baʕi:r/ (camels).

The Bedouin Arabic dialects are characterised by a greater degree of emphasis if compared to urban dialects (Kaye and Rosenhouse 1997). This could suggest that in the case of Bedouin dialects the effect of the emphatic consonants on adjacent segments (e.g., the formant frequencies of adjacent vowels) will be greater than in the case of urban dialects.

2.2. The nature of emphasis

Emphasis has been regarded as a well-known characteristic of Arabic, the language that is called the language of /ḍa:d/, the name of the emphatic consonant /ḍ/. The study of emphasis dates back to the work of early Arab grammarians of the middle Ages. The vast majority of Arabic dialects nowadays are known to have emphatic vs. non-emphatic contrasts apart from a few dialects such as Maltese, Chadian, Nigerian Arabic (some speakers), Juba Arabic, Ki-Nubi, and Cypriot Arabic (Hetzron 1997). Arabic still maintains the full set of emphatics developed from Proto-Semitic (Finch 1984; Versteegh 1997; Watson 2002). They are evolved from the Proto-Semitic ejectives. The ejectiveness of the emphatics was altered into a pharyngeal constriction in Arabic (Cantineau 1960 as cited in Heselwood 1996).

The emphatic consonants are distinguished from their plain counterparts by the presence of a secondary articulation in addition to the primary articulation which characterises both classes. This secondary articulation determines a phonemic distinction between the two classes in Arabic phonology. Each of the emphatic and plain consonants obtains its phonological identity from being opposed to the other (Obrecht 1968; Trubetzkoy 1969). For example, the Arabic word /ṭi:n/ (mud) with an emphatic /ṭ/ forms a minimal pair with the word /ti:n/ (fig).

In the 8th century Sibawayh used some terms to refer to the emphatic consonants. These terms include "mutbaqa" (covered), "musta^cliyah" (raised) and "mufaxxama" (thickened) (Al-Nassir 1993). According to Sibawayh, "itbaq" (covering) is associated with covered sounds such as /ṭ ḍ ð̣ ṣ/ as in their production the tongue is covered by the palate from the primary place of articulation to the place where it is raised towards the soft palate (Al-Nassir 1993). The term "musta^cliyah" has a double reference to covered sounds and uvulars /q χ ʁ/ and is used due to the fact that the tongue is thought to be raised towards the velum in the production of both covered and uvular sounds. The term "itbaq" describes sounds that have two places of articulation, whereas "musta^cliyah" describes the primary articulation of /q χ ʁ/ and the secondary articulation of the coronal emphatics.

Terms like "mufaxxama" (thickened) were also adopted by some phonologists like Jakobson (1957) to distinguish the emphatic from the non-emphatic consonants. The emphatic consonants, according to Jakobson, constitute part of a group of consonants requiring a constriction in the pharynx somewhere between the velum and the glottis. They include the emphatics /ṭ ḍ ṣ ẓ/, the uvulars /q χ ʁ/ and the pharyngeals /ħ ʕ/. The term "mufaxxama", in this case, refers to consonants that have a constricted pharynx regardless of whether this constriction is a primary or a secondary articulation.

The following section examines in more detail the emphatic consonants in Arabic, their classification and the criteria upon which this classification is based.

2.3. The Arabic emphatics

The only emphatic consonants in classical Arabic with a phonemic function are /ṭ ḍ ð̣ ṣ/ (Card 1983; Haddad 1984). These four consonants correspond to the four consonants referred to by Sibawayh as "mutbaqa" (covered) in his 8th century treatise, Al-Kitaab (Al-Nassir 1993) and they are orthographically represented by the Arabic letters ط, ض, ص and ظ respectively. The set of emphatics in Iraqi Arabic are also the same as those in classical Arabic (Al-Ani 1970). However, in other Arabic dialects, the number of emphatics differs (Al-Ani 1970). There is disagreement among researchers with respect to what consonants can be included in the emphatic category as discussed later in this section.

The emphatics in Egyptian Arabic, for instance, are classified by Harrell (1957) into the categories primary, secondary and marginal. Primary emphatics such as /ṭ ḍ ṣ ẓ/, as compared to other emphatics, are phonemic and the most frequent in terms of occurring in all positions and in all vocalic contexts. The secondary emphatics can occur in the context of the primary emphatics /ṭ ḍ ṣ ẓ/ and are referred to as conjunct secondary emphatics. The secondary emphatics that occur in contexts other than those of the primary emphatics are referred to as independent secondary emphatics. Secondary emphatics which may include consonants like /ṛ ḷ ḳ ḅ/ are rare and have limited distribution. The secondary and marginal emphatics seem to be similar given that the occurrence of both depends on the presence of a primary emphatic elsewhere in the word as in [saṭṛ] or the low vowel /a/ as in [mɑṛ:o] (pass). However, Harrell categorises some consonants as marginal emphatics due to the difficulty in finding contrastive examples between these emphatic and non-emphatic consonants. In this case, some consonants, e.g., /g f n h/ can be emphatic in the context of a secondary emphatic or in stylistic emphatic speech.

Researchers like Ghazali (1977), Card (1983), and Laradi (1983) also adopt the primary-secondary distinction in their classification of the emphatics. Card (1983) refers to the primary emphatics as those phonologically and originally emphatic and the secondary emphatics as those acquiring emphasis by spreading. According to Ghazali (1977), the primary emphatics have some features in common that make them different from the so-called secondary emphatics. These features include:

1. they display similar articulatory and acoustic features
2. they affect adjacent segments in similar ways
3. they are capable of occurring in different vocalic contexts without losing their phonemic status.

A more detailed discussion on the different emphatics as realised in different dialects will follow in sections 2.3.1 and 2.3.2.

2.3.1. The primary emphatics

Although one can identify a set of primary emphatics that are the most frequently occurring emphatic phonemes in Arabic, this set tends to vary across dialects and sometimes within the same dialect. Over the next few paragraphs we review the different groups of sounds that have been considered as the core primary emphatics. The set of emphatic consonants reported for classical Arabic differ from that introduced by Harrell for Egyptian Arabic as primary emphatics in that classical Arabic emphatics include /ð̣/ instead of /ẓ/ (see section 2.3).

The primary emphatics, which exist in a certain dialect, are grouped together since certain emphatics are consistently present in one dialect, but not the other. The first group include the emphatics /ṭ ð̣ ṣ/. These emphatics are identified by Maamouri (1967) and Ghazali (1977) for Tunisian Arabic, Ali and Daniloff (1972b, 1974) for Iraqi Arabic, Hussain (1985) for Gulf Arabic, Bukshaisha (1985) for Qatari Arabic, Davis (1995) for the southern rural variety of Palestinian Arabic, Daher (1998) for Damascus Syrian Arabic and Abumdas (1985) for Benghazi and Zliten varieties of Libyan Arabic. The second group contains the emphatics /ṭ ḍ ṣ ẓ/ which are reported by Gairdner (1925), Harrell (1957), Lehn (1963), Royal (1985) and Youssef (2006) for Egyptian Arabic, Nasr (1959) and Obrecht (1968) for Lebanese Arabic, Laradi (1972, 1983) for Tripoli Libyan Arabic, Card (1983) and Herzallah (1990) for Palestinian Arabic, Ahmed (1984) for colloquial Sudanese Arabic, Zawaydeh

(1998) for Jordanian Arabic and Bakalla (2002) for Meccan dialect of Saudi Arabic.

It is clear that neither /ḍ/ nor /ẓ/ exists in the first group while /ð̣/ is not included in the second group. This is because the emphatic /ḍ/ can be realised as [ð̣] as in San'ani Arabic of Yemen (Watson 2003) and in some Libyan dialects (Abumdas 1985). Furthermore, /ẓ/ may have limited occurrences in some Arabic dialects. For instance, Davis (1995) reports the marginal occurrence of /ẓ/ in the southern rural variety of Palestinian Arabic.

In fact, there is a complementary distribution in the occurrence of /ð̣ ẓ ḍ/ in the Arabic dialects. For instance, the classical Arabic emphatic /ð̣/ is realised as [ẓ] in Egyptian Arabic (Mitchell 1990), Syrian colloquial Arabic (Newman 2002), Lebanese Arabic (Obrecht 1968) and in urban Palestinian (Jerusalem) Arabic (Card 1983) and as [ḍ] in Moroccan Arabic (Rajouni et al 1987) and Tripoli Libyan Arabic (Laradi 1983). Shahin (1996) lists [ð̣] for the rural Abu Shusha dialect of Palestinian Arabic while Herzallah (1990) lists [ẓ] for urban Palestinian Arabic.

The lack of the emphatic /ð̣/ in Cairene Arabic was reported by Watson (2003) as the outcome of a merger of the voiced emphatic interdental fricative and the voiced emphatic dental stop into an emphatic dental/alveolar stop. The historical loss of the classical Arabic fricative phonemes /θ ð ð̣/ in Cairene Arabic paved the way for Cairene Arabic to develop the voiceless /s/-/ṣ/ and

/t/-/ṭ/ oppositions in addition to the voiced /d/-/ḍ/ and /z/-/ẓ/ oppositions (Watson 2002).

Heselwood (1996) indicates that /ẓ/, which is mistakenly viewed as a phonemic split of /ð̣/, seems to have its historical origin in the 16th century; it is the Ottomani pronunciation of the Arabic /ð̣/. Heselwood adds that the voicing of /ẓ/ has a distinctive function in Egyptian Arabic due to the existence of the voiceless phoneme whereas the voicing of /ð̣/ lacks the contrastive function in Baghdadi Arabic because there is no voiceless interdental emphatic in this dialect.

There are not as many examples for the /z/-/ẓ/ contrasts in the Arabic dialects as there are for the emphatics /ṭ ḍ ð̣ ṣ/ and their non-emphatic counterparts. Harrell (1957) gives a minimal pair to show the contrastive function between /z/ vs. /ẓ/ as in /zu:r/ (visit (m. sg.)) and /ẓu:r/ (perjury) in Egyptian Arabic. Moreover, Dickins (1996) provides the following minimal pairs to show the phonemic contrast between the emphatics /ḍ/ and /ẓ/ in the same dialect:

(1) /ʔiḍ:al:im/ (to be made dark) vs. /ʔiẓ:al:im/ (to make a complaint)

(2) /ḍarab/(to hit) vs. /ẓarab/ (to crap).

However, in Tripoli Libyan Arabic, Laradi (1983) indicates that /ḍ/ and /ẓ/ are used interchangeably instead of /ð̣/, giving this example: /ẓa:bit/ or /ḍa:bit/ (officer).

It is important at this point to mention that the Arabic /ṭ/ may have been voiced in the past especially if considering both Sibawayh's treatment of this sound as "majhuur" (voiced) (Al-Nassir 1993) and the diachronic study carried out by Garbell (1958). According to Sibawayh, /ṭ/ with no "itbaq" (covering) would be realised as /d/ (El-Saaran 1951; Al-Nassir 1993). Garbell (1958) assumes that this sound was voiced until the ninth or tenth century A. D. This shows that there is historical evidence for the voicing of /ṭ/. In fact, there are voiced variants of a non-geminated /ṭ/ in some varieties of Yemeni Arabic (Watson 1993), and /ṭ/ is voiced word-initially and intervocalically in San'ani Arabic of Yemen (Watson 2003). Blanc (1978) regards the Yemeni /ṭ/ as having both voiceless and voiced allophones. Hetzron (1997) provides examples from Yemeni Arabic for a voiced intervocalic /ṭ/ as in [maḍar] (rain) and [baḍ:a] (duck).

In this study the term primary emphatics is employed to refer to /ṭ ḍ ð̣ ṣ ẓ/ and the others are referred to as secondary. These emphatics are coronal emphatics with their primary articulation being dental or alveolar, depending on the Arabic dialect concerned. El-Dalee (1984) refers to the emphatic dentals as the best class to carry the feature [retraction] contrastively without any ambiguity.

2.3.2. The secondary emphatics

The secondary emphatics are found in some, but not all Arabic dialects. Their number may also vary from dialect to dialect. Lebanese Arabic, for instance, is reported to have the secondary emphatic consonants /ḅ ṃ ṇ ḷ ṛ/ in addition to the primary emphatics referred to in section 2.3.1 (Obrecht 1968). The same emphatics are presented by Nasr (1959) for Lebanese Arabic apart from /ḅ/. Obrecht (1968) refers to an example of an emphatic /ḅ/ in /ḅa:ḅa/ (pope), a near minimal pair containing /ṇ/ vs. /n/ in /ṇa:j/ (wooden flute) and /na:ji/ (uncooked) and a minimal pair containing /ḷ/ vs. /l/ in /ʔaḷ:a/ (God) and /ʔal:a/ (he said). It is worth noting that some of these words are not originally Arabic words (e.g., pope), but are rather borrowed words and the contrast is limited to the context of the low vowel. Nevertheless, these examples indicate that the secondary emphatics may have a phonemic role. The following example of the emphatic /ṃ/ as opposed to /m/ is given by Nasr (1959) for Lebanese Arabic: /mai/ (a name of a girl) vs. /ṃai/ (water).

The treatment of certain segments as emphatics is sometimes based on phonetic rather than phonological grounds. For instance, phonetic evidence represented by F2 lowering in the context of /ḅ ṃ ḷ/, compared to their non-emphatic counterparts, was reported by Card (1983). This led Card to treat /ḅ ṃ ḷ/ as emphatics in Palestinian Arabic, but there is a dispute over their role in the phonological system. Moreover, the so-called secondary emphatics may not display the phonetic features associated with the primary emphatics in all dialects. The classification of /ḅ ṃ ḷ/ as emphatics in Tunisian Arabic and some other Arabic dialects was therefore rejected by Ghazali (1977) since their occurrence is associated with the low back vowel and they were not found to induce the retraction of adjacent segments. The following section discusses the emphatic nature of the low back vowel.

2.3.2.1. The emphaticness of the low vowel /ɑ/

The low back vowel involves a pharyngeal constriction similar to that of the emphatic consonants (Delattre 1971; Laradi 1983). So if it occurs next to consonants like /b m l/, the quality of this vowel is superimposed on these consonants, enhancing the auditory impression of emphasis (Ghazali 1977). As the low vowel [ɑ] is the only underlying emphatic vowel in Cairene Arabic, Youssef (2006) suggests that it is unavoidable for all consonants to be emphatic in a syllable containing this vowel, which accordingly spreads emphasis to adjacent segments. Youssef regards the traditional secondary emphatics as being underlyingly plain consonants that acquire emphasis from [ɑ] through a coarticulatory process.

A possibility of the /a(:)/ category being split into emphatic and plain vowels is discussed by Ferguson (1956), who makes reference to emphatic and plain forms of /m b l/, which are phonemically contrastive only in the context of /a(:)/. Thus, the phonemic function may be better attributed to this vowel. There is also, according to Ghazali (1977), a possibility of having an /æ/-/ɑ/ phonemic split in the western dialects of Arabic, attributing this to factors like sound change and borrowed words which retain their low back vowel in words like /bɑ:bɑ/ (father) borrowed from French and /lɑ:mp/ (lamp) from Italian. Ghazali (1977) provides a minimal pair from Tunisian Arabic that shows how borrowings lead to the establishment of the phonemic distinction between /gæz/ (Kerosene) and /gɑz/ (butane).

In the phonological study of Zliten Libyan Arabic (ZLA) carried out by Abumdas (1985), the distinction between the low front and low back vowel is considered to be totally phonemic in contexts of the so-called secondary emphatics as shown by the examples in Table 2.2.

Table 2.2. The phonemic contrast between /a(:)/ and /ɑ(:)/ in ZLA (Abumdas 1985)

vowel	word	meaning	vowel	word	meaning
/a/	/bal:ah/	he wet	/ɑ/	/bɑl:ɑh/	by God
/a/	/wal:a/	he returned	/ɑ/	/wɑl:ɑ/	by God
/a/	/kaf:/	palm of the hand	/ɑ/	/kɑf:/	onomatopoeia of falling objects
/a:/	/ba:bah/	his door	/ɑ:/	/bɑ:bɑh/	father
/a:/	/ʒa:ri/	running	/ɑ:/	/ʒɑ:ri/	my neighbour
/a:/	/ba:ni/	builder	/ɑ:/	/bɑ:ni/	family name
/a:/	/ba:lah/	his attention	/ɑ:/	/bɑ:lɑh/	bundle, bale
/a:/	/ba:di/	starting	/ɑ:/	/bɑ:di/	family name
/a:/	/ga:l/	he exempted	/ɑ:/	/gɑ:l/	he said

Abumdas (1985) discusses two possible choices to solve the phonemic problem in the examples in Table 2.2: either to ascribe the phonemic role to the consonant, treating it as an emphatic, or to the low back vowel. For economic purposes in the consonantal inventory of the dialect, Abumdas prefers the latter choice although he states that Arabic developed minimal pairs of the secondary emphatics /ḅ ṃ ṇ ḷ ṛ/ in the context of a low vowel.

Laradi (1983) initially treats /a:/ and /ɑ:/ as separate phonemes in Tripoli Libyan Arabic (TLA), while noting that the phonemic /ɑ:/ is an open centralised vowel with a limited occurrence. But since the examples in Table 2.3 contain /r/, Laradi (1983) later argues that [ɑ:] could be an allophone of /a:/ that is backed in the context of /r/. While the backing of /r/ can therefore be ascribed to the vocalic context of the low vowel like for any other secondary emphatic consonants, this has remained an open debate.

Table 2.3. The phonemic contrast between /a:/ and /ɑ:/ in TLA (Laradi 1983)

vowel	word	meaning	vowel	word	meaning
/a:/	/da:r/	he did	/ɑ:/	/dɑ:r/	room
/a:/	/ma:r/	common	/ɑ:/	/mɑ:r/	passing
/a:/	/ħa:r/	puzzled	/ɑ:/	/ħɑ:r/	hot (m. sg.)

On the other hand, the low back vowel is accounted for in a different way in the context of a primary emphatic. It is an allophone of the low front vowel in the emphatic context and acquires its backing from these consonants (Ghazali 1977; Laradi 1983; Abumdas 1985). Ghazali (1977) indicates that the occurrence of a primary emphatic consonant next to a low vowel is a sufficient condition for the emphaticness of the latter. Laradi (1983) provides the example words [ḍɑ:r] (harmful), [ṭɑ:b] (it cooked) and [ṣɑ:m] (he fasted) from Libyan Arabic in which the low back vowel is treated as an allophone of /a:/ in the context of the primary emphatics.

This section has provided two different views concerning the emphaticness of the low vowel /a(:)/. In the context of the primary emphatics, a back allophone of this vowel is thought to occur, while in the context of secondary emphatics, researchers disagree on whether the low back vowel is phonemic and spreads emphasis in the consonant or whether it is still an allophone of /a(:)/. The following sections shed some light on some secondary emphatics and their relation to this low vowel in addition to other consonants that are classified as emphatics.

2.3.2.2. The emphaticness of /ḷ/

There is more agreement on the phonetic existence of the emphatic [ḷ] than on its phonological role which depends, to a large extent, on the dialect concerned. The treatment of [ḷ] as a primary pharyngealised emphatic in TLA, for instance, is based on radiographic and endoscopic examination of [ḷ] which displays the physiological features of pharyngealisation as well as on Laradi' s intuitions as a native speaker of TLA, but not on phonological grounds (Laradi 1983). From a systematic point of view, this emphatic differs from other emphatic (pharyngealised) sounds in that its occurrence is restricted to the context of /a/ or /a:/ in most dialects. Therefore /ḷ/ has more features in common with secondary emphatics like /ḅ/ and /ṃ/ than with those of the primary emphatics. Its occurrence is often associated with the name of God /ʔaḷ:ah/ and its derivatives (Gairdner 1925; Lehn 1963; Laradi 1983).

In TLA, the emphatic [ḷ] seems to be not more than an allophone of /l/ although Laradi (1983) does not explicitly indicate that. As discussed in section 2.3.2.1, Abumdas (1985) supports the phonemic role of the low back vowel at the expense of the emphatic [ḷ] which he describes as velarised in the context of a primary emphatic, e.g., [maṣḷu:b] (crucified) and in the context of a low back vowel, e.g., [baḷ:ɑ] (by God)

In Baghdadi Arabic, Giannini and Pettorino (1982) do not regard /lˠ/ as an emphatic consonant. This is due to phonetic and phonological reasons. First it is not articulatorily and acoustically similar to the other emphatics which are pharyngealised; the evidence rather points to its velarisation. It is clear that Giannini and Pettorino associate emphasis with pharyngealisation. The discussion in section 2.4.2 shows that the secondary articulation of the emphatics can be realised as velarisation, uvularisation or pharyngealisation. Secondly, /lˠ/ does not function distinctively with its non-velarised counterpart; therefore it is regarded as an allophone of /l/.

Some researchers provide examples to show the phonemic role of the emphatic /ḷ/, but most examples are associated with the context of the low vowel. Al-Ani (1970), for instance, indicates that this emphatic exists in modern Iraqi Arabic as in the minimal pair /waḷ:a:h/ (by God) and /wal:a:h/ (he appointed him). Similarly, Ferguson (1956) argues that the emphatic /ḷ/ in classical Arabic (CA) and modern Arabic dialects must be treated as a separate phoneme, giving examples of minimal pairs to support its phonemic function, but looking at these examples in Table 2.4, it is clear that they all contain the low vowel.

Table 2.4 The phonemic role of /ɫ/ in CA and some Arabic dialects (Ferguson 1956)

dialect	example words of /ɫ/	meaning	example words of /l/	meaning
CA	/waɫ:a:hu/	and God	/wal:a:hu/	he appointed him
SYA	/waɫ:a/	by God	/wal:a/	he appointed
MA	/ɫ:a/	God	/l:a/	no
SUA	/qaɫ:/	raise	/qal:/	diminish
IA	/xaɫ:i/	my vinegar	/xal:i/	leave, let
IA	/xa:ɫi/	my uncle	/xa:li/	empty, deserted

In the Arabic dialects examined by Ghazali (1977), only Iraqi Arabic has phonological and phonetic evidence for the emphatic /ɫ/, e.g., in /xa:ɫi/ (uncle) versus /xa:li/ (deserted). Ghazali reports no difference between these words in Egyptian Arabic where both are realised as [xa:li]. The most interesting observation is that, according to acoustic evidence, only /l/ in Iraqi Arabic carries the distinction between the two words, but not the vowel. In both words, /a/ displays similar formant frequencies (F1 = 700 Hz, F2 = 1500 Hz), but /l/ has an F2 of 1500 Hz and /ɫ/ has an F2 of 1000 Hz with a large F2 transition for the following vowel [i].

In Gulf Arabic, the emphaticness of /ɫ/ is also supported phonologically and phonetically (Hussain 1985). The phonemic function of /ɫ/ is illustrated by the following minimal pairs which show the occurrence of the emphatic /ɫ/ in the environment of both the front short vowel /i/ and low short vowel /a/:

(1) /xiɫ:i/ (my vinegar) vs. /xil:i/ (my mistress)
(2) /waɫ:a/ (to flee) vs. /wal:a/ (by God).

Some Arabic dialects have developed an emphatic /ḷ/ from borrowed words. One typical example borrowed by Moroccan and Cairene Arabic from Italian is /ḷɑmp/ (lamp) (Ahmed 1984).

2.3.2.3. The emphaticness of /ṛ/

This section examines the so-called emphatic /ṛ/ which is found to have some special features as compared to other emphatics. The existence of this emphatic with a phonemic function is reported, for instance, by Harrell (1957) as shown in the examples /bar:i/ (pertaining to land) and /baṛ:i/ (my land) from Egyptian Arabic in which /baṛ:i/ has an emphatic geminate /ṛ:/. This emphatic is found to differ from the other underlying emphatics /ṭ ḍ ṣ ẓ/ in that it is subject to morphophonemic alternations with its non-emphatic counterpart as shown by the following examples from Davis (1991):

(1) /kabi:r/ (big (sg.)) vs [kubɑ:ṛ] (big (pl.))
(2) /laṭi:f/....(pleasant (sg.)) vs. [luṭɑ:f] (pleasant (pl.)).

In example (1) /r/ in the singular form /kabi:r/ is not emphatic in the context of /i:/ while it is emphatic in the context of /ɑ:/ in the plural form [kuba:ṛ]. This shows how changing the word morphology changes the vowel and thus affects the realisation of a segment as emphatic or not. On the other hand, in (2) in both singular and plural forms the emphatic /ṭ/ remains emphatic. Thus /ṭ/ is underlyingly emphatic while the emphaticness of [ṛ] is conditioned by the context which is governed by morphological rules. In Gulf

Arabic, /r/ is backed when it occurs next to segments that have posterior articulation such as pharyngeals, uvulars, emphatics and low back vowels (Hussain 1985). This provides further support for the emphaticness of the low back vowel.

Ghazali (1977) also regards [r] as having an irregular behaviour, giving the following examples to show that this alteration exists also in Tunisian Arabic conjugation between first and third person for /r/, but not for /ṭ/:

(1) [ṛɑː] (he saw) vs. [riːt] (I saw)
(2) [ʕṭɑː] (he gave) vs. [ʕṭiːt] (I gave)

It is clear that backing in /ṛ/ is contingent on the context of the low back vowel while /ṭ/ does not lose its backing or pharyngealisation in different vocalic contexts. It may be argued that because [ṛ] does not retain its emphasis in the context of a high front vowel it means that it is not underlyingly emphatic, but rather has an allophonic variant in the context of the low back vowel. Harrell (1957) declares that [ṛ] occurs mostly with low vowels as he could not provide examples of [ṛ] occurring in the vocalic context of /iː eː uː oː/.

Similarly, in Palestinian Arabic [ṛ] is treated as a primary emphatic consonant that is subject to de-emphasisation in some contexts (Younes 1993; Younes 1994). Younes (1994) provides examples for the emphaticness of [ṛ] which is associated with a low vowel as in [ɣuṛɑf] (rooms) and on the de-emphasisation of [ṛ] in the context of a high front vowel [xirfæːn] (lambs) or in the context of a coronal plain consonant as in [bærdæ:n] (cold) (Younes 1994).

In Tunisian Arabic, the emphatic [ṛ] differs from the pharyngealised /ṭ/ (Ghazali 1977) in the sense that [ṛ] is articulatorily and acoustically similar to the American English retroflex described by (DeLattre 1971); it has a retroflex articulation and characterised by a lowered third formant. Ghazali (1977) concludes that the realisation of [ṛ] as front or back depends on the adjacent segments in the eastern Arabic dialects whereas a back retroflex [ṛ] rather than a pharyngealised consonant can be found in the Arabic dialects spoken in the North Africa and its presence is independent of a back segment. As there is no contrastive function between retroflexion and pharyngealisation and there is an articulatory and acoustic similarity between both, the back [ṛ] may be subject to misinterpretation as a pharyngealised segment.

2.3.2.4. Other emphatics

Some researchers extend the list of the emphatic consonants to include other sounds, but this is often disputed. This list includes the uvulars /q χ ʁ/ and the pharyngeals /ħ ʕ/ (Jakobson 1957; Trubetzkoy 1969; Al-Nasser 1993). These phonological studies tend to equate back articulations with emphasis, considering uvulars and pharyngeals to be emphatics (Jakobson 1957; Lehn 1963; DeLattre 1971).

The phonological classification of /w/ as the emphatic counterpart of /j/ also seems to associate back articulations with emphasis (Heselwood

1992). The semi-vowel /w/ is a back articulation as compared to /j/. Harrell (1957) claims that both /w/ and /j/ can occur as marginal emphatics whose phonetic occurrence is possible either in the context of other emphatics or in stylistically emphasised pronunciation of words which are not normally pronounced as emphatics.

Some researchers argue for classifying the uvular /q/ as an emphatic consonant. For instance, Jakobson (1957) claims that /q/ has two places of articulation by treating it as a velar sound produced with pharyngealisation in the same way as /tˤ/ being post-dental and pharyngealised. Other researchers group the velar plosive /k/ with the uvular plosive /q/ in a way similar to the other emphatic and non-emphatic counterparts. For instance, Ali and Daniloff (1972b) treat the uvular /q/ for which they use the symbol /k̹/ as an emphatic counterpart of /k/ in Iraqi Arabic and so does Harris (1942) in his study of Moroccan Arabic, providing the minimal pair /kli:t/ (I ate) and /qli:t/ (I fried).

However, Harrell (1957) dismisses the possibility of treating /q/ as an emphatic consonant since its production involves a uvular, but not a pharyngeal articulation. Thus Harrell also associates emphasis with the presence of a pharyngeal articulation. Giannini and Pettorino also (1982) refuse to treat /q/ and /k/ as an emphatic and non-emphatic pair because /q/ does not display the articulatory features of the emphatics. They indicate that the distinction between /q/ and /k/ lies in the different place of articulation (uvular /q/ vs. palato-velar /k/).

Ghazali (1977) studied the phonetic properties of the segments that have back articulations, but similar to Giannini and Pettorino (1982) classified as emphatics only the coronal pharyngealised consonants. Ghazali (1977) argue that classifying uvulars and pharyngeals as emphatic consonants has no justification either from an articulatory or from a coarticulatory point of view. Uvulars and pharyngeals have only a primary place of articulation whereas pharyngealised consonants have a primary and a secondary place of articulation.

Furthermore, uvulars and pharyngeals have a limited effect on the neighbouring segments. For instance, Ghazali (1977) indicates that the backing induced by the pharyngealised emphatic consonants is greater than that induced by uvulars and pharyngeals. As a result, the F2 drop for the vowel in the pharyngealised context is considerable if compared to that in the context of a uvular or a pharyngeal consonant. This could be the reason why Ferguson (1957) treats uvulars as semi-emphatics due to their limited effect on adjacent segments; for instance, in some dialects spoken in Moroccan Arabic, the vowel /a/ is realised as a back allophone similar to that associated with the emphatic consonants, but this is not the case when /a/ follows uvulars.

The criteria for classifying a consonant as an emphatic is built on phonetic grounds related to the pharyngealisation of a consonant according to Ghazali (1977 and Giannini and Pettorino's (1982); only pharyngealised consonants are included as emphatic consonants. Emphasis is attributed to the secondary articulation since this constitutes the main phonetic feature that distinguishes the emphatic from the non-emphatic consonants.

2.3.3. Summary of the Arabic emphatics

Some of the emphatics play an essential role in the phonetics and phonology of the vast majority of Arabic dialects and are referred to as primary emphatics, e.g., /ṭ ḍ ð̣ ṣ ẓ/. These emphatics have a contrastive function with their non-emphatic counterparts and thus they add a set of phonemes to the phonology of Arabic dialects. There may also be emphatic variants of /l r n m b/ in some Arabic dialects, but they do not seem to be underlyingly emphatic, but rather acquire emphasis from other emphatic segments like the adjacent low back vowels. They are referred to as secondary emphatics. The phonemic function of the secondary emphatics is questioned and limited examples are provided for some dialects. Some phonological studies classify uvulars, pharyngeals and other back articulations as emphatics due to the phonetic similarity they share with the emphatics while others refute this classification, providing phonetic evidence for the differences between the two classes.

The following sections are dedicated to the phonetic representation of the emphatic consonants. These include the articulatory, acoustic and perceptual features of this class of consonants.

2.4. Articulatory features

The articulation of the emphatic consonants requires two articulatory gestures, namely primary and secondary. This section will review these articulations. There is also a focus on other articulatory correlates of emphasis in addition to the articulatory difference between pharyngeals and pharyngealised consonants.

2.4.1. The primary articulation

The emphatic consonants have a coronal primary articulation in the dental and/or the alveolar area. This section sheds some light on whether the secondary articulation of the emphatics influences the primary articulation. Some researchers indicate that the backward movement of the tongue towards the back wall of the pharynx could cause the retraction of the tongue tip and/or blade from its usual position in the area of the inside part of the upper front teeth and/or the alveolar area (e.g., Gairdner 1925; Marçais 1948 as cited in Norlin 1987; Odisho 1973; Ghazali 1977; Laradi 1983; Bukshaisha 1985; Hussain 1985). Other researchers, however, indicate that both sounds have the same primary articulation (e.g., Harrell 1957; Norlin 1987; Laufer and Baer 1988; Kriba 2004).

A study on Algerian Arabic based on palatograms has shown that the tongue tip is retracted (about 8 millimetres) to the alveolar area for /ṭ/ as compared to /t/ (Marçais 1948 as cited in Norlin 1987). Similar results are reported for the emphatics in Egyptian Arabic (Gairdner 1925) and Iraqi Arabic (Odisho 1973) although Odisho uses the term "denti-alveolar" to refer to both the emphatic and plain consonants.

Some researchers differ in locating the primary articulation for the plain and emphatic consonants, but agree on the presence of retraction for the latter class. For instance, Finch (1984) describes the non-emphatics as post-dentals and emphatics as alveolars while Al-Ani (1970) treats the plain /t d s/ as dentals and their emphatic counterparts /ṭ ḍ ṣ/ as post-dentals in Baghdadi Arabic. Hussain (1985) indicates that /s/ is alveolar and /ṣ/ is post-alveolar in Gulf Arabic. On the other hand, Al-Ani (1970) treats both the emphatic /ð̣/ and plain /ð/ as inter-dental fricatives. This could be because the fact that they are inter-dental requires the tongue tip to be inserted between the upper and lower teeth to give them the phonetic feature associated with such an articulation.

The slight retraction of the tongue tip for /ṣ/ compared to /s/ is reported by Ghazali (1977), but he indicates that this difference in the dental-alveolar area does not have any apparent acoustic effect. This articulatory and acoustic account is not based on experimental evidence, and Ghazali's description of the slight articulation of the primary articulation for /ṣ/ seems to be based on his experience as a native speaker of Tunisian Arabic. As the retraction is slight, Ghazali speculates that it does not lead to any acoustic effect. The slight retraction of the primary articulation for the emphatic consonant is confirmed by palatograms of Libyan Arabic consonants (Laradi 1983) and by electropalatographic investigation of Qatari Arabic (Bukshaisha 1985).

Other researchers claim that the plain sounds and their emphatic counterparts have the same place of articulation (Harrell 1957; Norlin 1987; Laufer and Baer 1988), but this claim is not based on experimental work. Harrell (1957) rejects the claim made by Gairdner (1925) concerning the retraction of the tongue tip to the alveolar ridge in the production of the emphatic sounds in Egyptian Arabic due to lack of evidence although Harrell's (1957) own classification of the plain and emphatic consonants as dentals is not based on experimental work, but on individual observation. Most researchers' articulatory assessment of the primary articulation of the emphatics is based on impressionistic and personal intuitions.

In Libyan Arabic, direct palatography shows that both classes are dental (Kriba 2004). This does not agree with Laradi's (1983) results for Libyan Arabic as mentioned above in this section. Kriba (2004) notes that for some cases the contact made by both the tip and the blade of the tongue against the inside part of the upper front teeth extends to cover only the very beginning of the alveolar area for both classes. This effect is not considerable enough, covering only the area in the alveolar ridge adjacent to the border with the teeth so it is appropriate to regard the two groups as dentals.

The secondary articulation may cause the retraction of the tongue tip if the tongue tip movement is not independent from the posterior part of the tongue. Hardcastle's (1976) account of the anatomy and physiology of the tongue, however, suggests the relative independence of the tongue tip/blade system from the posterior part of the tongue. This is because the movement of these parts of the tongue seems to be controlled by different muscles. The anatomical information shows that the tongue consists of two parts, namely the oral and the pharyngeal (Hardcastle 1976); the oral part could move freely in the mouth and is loosely connected to the floor of the mouth by means of a membranous fold referred to as the frenulum. On the other hand, the pharyngeal part of the tongue is attached to the hyoid bone by muscles and to the styloid process of the skull. Thus this part of the tongue is positioned just in front of the epiglottis, and the median and two lateral glossoepiglottic folds connect both. Furthermore, Hardcastle (1976) indicates that the longitudinal muscles are responsible for achieving the retraction of the tongue tip. If this is the case, in the production of the emphatic consonants, the tongue tip and blade move independently from the posterior part of the tongue since its movement is controlled by different muscles, and thus they may not be affected by the tongue retraction towards the pharyngeal wall.

2.4.2. The secondary articulation

It is difficult to define the emphatic consonants in terms of simply having one secondary articulatory feature. Al-Nuzaili (1993) indicates that the articulation of the emphatic consonant is too complex to be described by a single feature. According to Lehn (1963), emphasis in Cairene Arabic entails a combination of articulatory correlates in addition to the primary articulation; the other articulatory correlates refer to the emphatics as being velarised, pharyngealised and labialised, and they are tenser than their plain counterparts.

The simultaneous occurrence of all these articulatory correlates may not always be associated with the production of the emphatic consonants as some of these features may be more enhanced than others because of factors related to the speaker and the phonetic context (Maamouri 1967) and possibly the dialect. It should also be noted that most experimental work focuses on the secondary articulation as represented by tongue retraction. Other researchers also indicate that rounding and protrusion of the lips are associated with the production of the emphatics (e.g., Jakobson 1957; Hetzron 1997). Harrell (1957) notes the additional feature of lip protrusion for the emphatics in colloquial Egyptian

Arabic, but indicates that lip protrusion does not cause lip rounding. This is contrary to the above-mentioned views, which evidently show that lip protrusion and rounding can occur together. Ghazali (1977) observes only slight protrusion of the lower lip of 2 to 3 mm for /ṭ/ and /ṣ/ compared to /t/ and /s/. On the other hand, Mitchell (1990) states that the position of the lips is neutral in the Arabic emphatics except for the classical style of speech which is characterised by rounding and protrusion of the lips, and the non-emphatics have spread lips.

It is also reported that there is an auditory similarity between pharyngealisation and labialisation. This explains why Bantu and Uzbek speakers replace a pharyngealised consonant by a labialised consonant when producing the Arabic emphatics (Jakobson 1957). These speakers have no pharyngealised consonants in their languages so they pronounce /tˤ/ as [tʷ] and /sˤ/ as [sʷ]. They exploit labialisation to produce a similar auditory effect to that induced by pharyngealisation. The fact that non-Arabs perceive the emphatic consonants as labialised may actually be accounted for by the rounding of the lips accompanying the production of the emphatic consonants (Hetzron 1997).

Labialisation (narrowing the front end of the oral cavity), velarisation and pharyngealisation (narrowing the back end of the oral cavity) are all given the feature [+flat] (Jakobson 1957; Jakobson et al 1969). The feature [flat] versus [plain] is among a set of binary distinctive features that are employed to distinguish between the phonemes of any language (Jakobson et al 1969). So a phoneme either holds the feature or not. Flatness is acoustically defined by the lowering of one or more formant frequencies (e.g., F2 for labialisation and pharyngealisation and F3 for retroflexion) (Jakobson et al 1969). According to this general description, phonemes with different articulatory correlates are included as a natural class, but this description is acoustically based on formant frequency lowering. This should not pose a problem in Jakobson's phonology given that these articulatory events do not contrast in a single language (Jakobson et al 1969). For instance, Jakobson argues that labialisation and pharyngealisation do not contrast in one language as it is not of importance to distinguish between formant frequency lowering induced by labialisation from that induced by pharyngealisation.

The state of the hyoid bone and the larynx may also be affected in the production of the emphatic pharyngealised consonants and regarded as other articulatory correlates of emphasis. Laradi's (1983) xeroradiographic results confirm the slight raising of both the larynx and the hyoid bone for the pharyngealised sounds in Libyan Arabic. As for Iraqi Arabic, Giannini and Pettorino (1982) speculate that the production of the emphatics is associated with elevating the hyoid bone, but not the larynx. In fact, Jones (1934) and Nolan (1983) report the association between narrowing of the pharynx and rising of the larynx. On the other hand, Ali and Daniloff's (1972a) articulatory investigation of Iraqi Arabic shows that the hyoid bone remains the same for both emphatic and plain consonants. For Tunisian Arabic, Ghazali (1977) observed no clear displacement of the hyoid bone for the pharyngealised consonants apart from its slight back movement due to tongue retraction. Ghazali also indicated that pharyngealisation did not lead to rising of the larynx which was reported for Algerian Arabic (Marçais 1948 as cited in Ghazali 1977).

Later work by Esling (1996, 2005) and Esling et al (2005) shows that pharyngeal constrictions are produced by shortening the supraglottic tube in addition to the retraction of the tongue and raising of the larynx. Although Esling (1996) points out that both the lowering and raising of the larynx are possible during a pharyngeal articulation, he later (1999) argues that larynx lowering in the articulation of pharyngealisation may occur, but it is regarded as a deviant tendency from an anatomical point of view and this position is not easy to retain.

In spite of the different articulatory correlates of emphasis, the basic realisation of the secondary articulation involves a backward tongue retraction that could vary from velarisation, uvularisation to pharyngealisation as discussed in the following sections. The emphatic consonants' basic secondary articulation is additional to the primary one and entails a constriction of a lesser degree than that of the primary one (Laufer and Baer 1988; Abercrombie 1967). Generally, the constriction for secondary articulations is of the type "approximant" (Catford 2001).

2.4.2.1. Velarisation

The view that the emphatic sounds are velarised originates from the Arab grammarian Sibawayh's impressionistic description of the classical Arabic sound system. Although Sibawayh does not directly refer to velarisation, the terms he uses to describe "itbaq" (covering) are compatible with velarisation as a secondary articulation and another primary articulation in the front of the vocal tract. Accordingly, the articulation of the emphatic consonants /ṭ ḍ ṣ ð̣/ is formed by both the back of the tongue against the velum and the front articulation (Al-Nassir 1993).

Among those who viewed the secondary articulation of the coronal emphatics as velarisation were Gairnder (1925) in Egyptian Arabic and Nasr (1959) in Lebanese Arabic. Other researchers also made reference to velarisation, e.g., Finch (1984) when referring to the Semitic languages, one of which was Arabic, Catford (1977) in some dialects of Arabic, and Ferguson (1956) in his description of the emphatic $/l^{\gamma}/$ in some Arabic dialects and Heffner (1969).

Some researchers report the co-occurrence of both velarisation and pharyngealisation in the production of the emphatics (Obrecht 1968; Catford 1977; Finch 1984; Ladefoged 2001). Furthermore, Abdul-Jaleel (1998) indicates that the production of the emphatics requires raising the tongue back against the velum and its retraction towards the pharyngeal wall. This suggests that both velarisation and pharyngealisation can coincide. Obrecht (1968) uses both velarisation and pharyngealisation to refer to the emphatics in Lebanese Arabic, although he confirms the presence of a pharyngeal constriction in their articulation. As a result, Obrecht is criticised by Laufer and Baer (1988) for not using the phonetic term "pharyngealisation" or the phonological term "emphatic" instead of velarisation. Arabic displays no phonological distinction between velarised and pharyngealised sounds.

Although Ladefoged and Maddieson (1996) classify the emphatics as pharyngealised sounds, involving a pharyngeal constriction halfway between the uvula and the epiglottis, they make it clear that these sounds could be velarised in some varieties of Arabic. Hussain (1990) regards the production of the emphatics as not restricted to pharyngealisation. It is reasonable to expect the emphatic consonants to have two secondary articulations like, for instance, pharyngealisation and labialisation due to the far distance between the places of articulation of both, whereas having velarisation with pharyngealisation simultaneously may not be possible.

The views that consider emphasis as a simultaneous occurrence of velarisation and pharyngealisation do not have an experimental basis, but are established on the basis of personal intuitions. Emphasis is realised as velarisation if the tongue back moves vertically towards the velum and as pharyngealisation if it moves horizontally towards the pharyngeal wall (ᶜUmar 1991 as cited in Habis 1998). Chomsky and Halle (1968) propose the feature high and back for velarised sounds and low and back for pharyngealised sounds like the Arabic emphatics. This description represents the directional movement for both articulations. Therefore, it may not be possible to suggest that both features coincide with each other since, according to Chomsky and Halle (1968), the production of pharyngealisation may contradict with that of velarisation as the former involves the tongue to be low as a function of the retraction towards the pharyngeal wall whereas the latter requires tongue raising towards the velum. This interpretation may lead to considering either of velarisation or pharyngealisation, but not a simultaneous occurrence of both.

A noteworthy point is that the description of the emphatics as velarised is not supported by articulatory studies. Although Giannini and Pettorino (1982) provide articulatory and acoustic evidence for a velarised lateral, they do not consider it as an emphatic (see section 2.5.1.1 in this chapter for more details).

As will be seen in the next two sections, results from articulatory studies provide evidence on the secondary feature of the emphatics as being uvularisation and/or pharyngealisation. The acoustic analysis carried out in this study suggests that the emphatic consonants have pharyngealisation as a secondary articulation (see discussion in chapter 7, section 7.5). This does not mean that the emphatic consonants may not have velarisation as a secondary articulation for some dialects. Formant frequency results from some studies provide information about a velar constriction (see also section 2.5.1.1). Thus different acoustic results for formant frequencies across different Arabic dialects may point to the different realisations of the secondary articulation of the emphatics.

2.4.2.2. Uvularisation

Uvularisation could be a possible secondary articulation for the emphatics as a number of researchers do indeed treat this category of sounds as uvularised (e. g., Al-Nassir 1993; McCarthy 1994; Catford 1977; Dolgopolsky 1997; Zawaydeh 1998; Zeroual 1999; Halle et al 2000). McCarthy (1994) and Halle et al (2000), for instance, describe the constriction of the upper pharynx displayed by the uvulars as being similar to that responsible for the emphatic consonants. This is why McCarthy (1994, p. 202) explicitly declares that "the so-called pharyngealised consonants of Arabic should really be called uvularised". This view is therefore based on an assumed articulatory similarity between the production of the emphatics and the uvular /q/. McCarthy's articulatory account of the emphatics is based on his own analysis of the articulatory results of Ghazali (1977). Thus, the secondary articulation of the emphatics is the same as the primary articulation of uvulars in Arabic. Catford (1977) also prefers to use the term uvularised rather than velarised and pharyngealised when referring to the emphatic consonants. Both McCarthy and Catford justify their classification of the emphatics as uvularised sounds because of the retraction of the tongue back towards the upper pharynx. It should however be noted that Ghazali's (1977) articulatory results show that the primary articulation of uvular represents a velo-pharyngeal constriction while the secondary articulation of the pharygealised consonants represents a mid-pharyngeal constriction between the place of uvulars and pharyngeals.

A fiberscopic study of Moroccan Arabic by Zeroual (1999) showed a similarity between the emphatics /ṭ/ and /ṣ/ and the uvular /q/. As a result, Zeroual (1999) classified the emphatics as uvularised. Zeroual mentioned nothing about the involvement of the pharynx in forming the constriction with the tongue, referring to the part of the tongue involved as the base. Similarly, Zawaydeh's (1999) endoscopic investigation of her speech identifies uvularisation as the secondary articulation of the emphatics.

Ali and Daniloff's (1972a, 1972b) studies of emphatics using high speed lateral cinefluorography showed that the secondary articulation of the emphatic consonants in Baghdadi Arabic involves the backward movement of the tongue back and root towards the back wall of the pharynx. Ali and Daniloff (1972a) played down the role of the velum and the back wall of the pharynx in the production of coronal emphatics, indicating that the tongue basically forms the pharyngeal constriction. Although this description seems to suggest pharyngealisation, Ali and Daniloff (1972a) declared that traditional terms like velarisation, pharyngealisation and laryngealization were not suitable for describing the emphatic articulation. This could support uvularisation as an alternative, particularly if examining their X-ray results (Ali and Daniloff 1972a) in which /ṭ/ had uvularisation accompanied by upper pharyngealisation.

Al-Nassir's (1993) description of his own /ṭ/ as presented on X-ray was also typical of a uvularised consonant. According to his analysis, the production of /ṭ/ involves moving the back part of the tongue towards the extreme part of the velum in addition to retracting the tongue root towards the upper pharynx. Similarly other researchers have reported an upper-pharyngeal constriction for the emphatics (Jakobson 1957; Card 1983; Finch 1984; Bukshaisha 1985; Davis 1995), yet they considered the emphatics as pharyngealised, not uvularised. Researchers may need to agree on how both uvularisation and pharyngealisation should be articulatorily represented in terms of the location of the constricted area in the pharynx.

2.4.2.3. Pharyngealisation

Pharyngealisation is also found to be an articulatory correlate of the emphatics in Arabic. This is evident in the way the studies surveyed refer extensively to terms like pharynx, pharyngealisation, pharyngeal cavity in their description of the secondary articulation of the emphatics. There are differences among researchers in determining the exact location of the constriction in the pharynx. The realisation of the emphatics as pharyngealised sounds has been experimentally investigated for Algerian Arabic (Marçais 1948 as cited in Giannini and Pettorino 1982), Iraqi Arabic (Al-Ani 1970; Giannini and Pettorino 1982), Tunisian Arabic (Ghazali 1977), Sudanese Arabic (Ahmed

1984), Qatari Arabic (Bukshaisha 1985), Libyan Arabic (Laradi 1983) and Jordanian Arabic (Kuriyagawa et al 1988; Al-Halees 2003).

Radioscopy of the vocal tract shows that the tongue root is retracted towards the back wall of the pharynx and the tongue back is moved away from the palate in Maghreb Arabic (Marçais 1948 as cited in Giannini and Pettorino 1982). This description corresponds to pharyngealisation as it involves the retraction of the tongue root towards the pharynx. A radiographic study conducted by Giannini and Pettorino (1982) shows similar results for the Baghdadi Arabic emphatics, as a constriction of about 3 mm is formed by the retraction of the tongue root towards the back wall of the pharynx at the level of the third and fourth cervical vertebrae. This is true for the emphatics /tˤ dˤ sˤ/.

A cinefluorographic study carried out by Ghazali (1977) on the emphatics of Tunisian Arabic provides evidence for tongue root retraction towards the middle part of the pharynx between the place of articulation of uvulars and the pharyngeals as high as the second cervical vertebra. Furthermore, an xeroradiographic investigation of Qatari Arabic shows tongue back retraction towards the back wall of the pharynx at the level of the second cervical vertebra along with the downward and backward movement of the tongue root (Bukshaisha 1985). Another xeroradiographic investigation of the Jordanian Arabic emphatics shows a pharyngeal narrowing, which reaches its maximum at the level of the second and third cervical vertebrae and extends across the whole pharynx (Al-Halees 2003). An X-ray photography of the emphatic /tˤ/ as produced by Iraqi and Jordanian speakers specifies the area of constriction as the mid to upper pharynx (Al-Ani 1970).

As for Sudanese Arabic, an electropalatophic investigation of the emphatics shows that the production of the emphatic consonants /tˤ dˤ sˤ zˤ/ is associated with the depression of the central part of the tongue and tongue retraction towards the pharyngeal wall (Ahmed 1984). Ahmed's lingual contact data does not show the exact location of the tongue in the pharynx; however, he formed his inferences about the retraction of the tongue towards the posterior wall of the pharynx from the reduced number of contacts in the posterior area of the palate.

Furthermore, an endoscopic analysis of the emphatic consonants in Libyan Arabic, Lebanese, Palestinian and Iraqi dialects of Arabic shows that the tongue root and the epiglottis are retracted towards the back wall of the pharynx, forming a pharyngeal constriction (Laradi 1983; Laufer and Baer 1988). The involvement of the epiglottis in the production of the emphatic as compared to their plain counterparts is also confirmed by the nasoendoscopic study of Jordanian Arabic (Heselwood and Al-Tamimi 2006). Thus the epiglottis could play a role as an articulator in the production of the emphatics in addition to the involvement of the tongue back and/or root.

The studies above suggest that the constriction for the secondary articulation of the emphatics can occur in the area between the velum, uvular and pharynx. In the pharynx, variation is also expected as the constriction may be in the upper, middle or lower part of the pharynx. It should be noted that articulatory studies are based on a limited number of speakers, so cross-speaker variability in the realisation of the secondary articulation is not investigated. For instance, the following studies are restricted to only one speaker: Ali and Daniloff (1972a); Ghazali (1977); Giannini and Pettorino (1982); Bukshaisha

(1985); Kuriyagawa (1988); Al-Nassir (1993); Zeroual (1999). Ahmed (1984) employs two speakers while Laufer and Baer (1988) use four speakers of Arabic, but they represent three dialectal areas, namely, Lebanese, Palestinian and Iraqi. The use of the small number of speakers seems to be attributed to the difficulty of carrying out articulatory studies and the discomfort associated with that; therefore not everybody is ready to participate in these studies. This could be the reason why some researchers employ themselves as the only subject in their studies (e. g., Ghazali 1977; Al-Nassir 1993). Another problematic issue is that most articulatory studies are conducted in foreign countries because it is not convenient to take the equipment used for articulatory studies back home where the native speakers are located. The inclusion of a small number of speakers may not represent the dialect or reveal the variability that may exist across speakers, yet a general idea about the secondary articulation is obtained.

2.4.3. Pharyngeal and pharyngealised consonants

It is well-known that both pharyngeals and pharyngealised consonants (emphatics) exist in Arabic in general and in Libyan Arabic in particular. The consonantal system of LA contains the pharyngeals /ʕ ħ/ in addition to the pharyngealised /tˤ dˤ sˤ ðˤ zˤ/ (see Table 2.5). These sounds display some kind of similarity since the production of both classes requires a pharyngeal constriction as their names suggest. However, there are phonetic differences between the two classes; one difference lies in the fact that pharyngealised consonants are characterised by an additional primary oral articulation (Younes 1993). Another difference is related to the fact that the secondary articulation of the emphatics has a higher location than that of the pharyngeal consonants (e.g., Ladefoged and Maddieson 1996; Zeroual 1999). Some of the work looking at these differences will be reviewed below.

Ghazali's (1977) cinefluorographic films show that the pharyngealised consonants have a mid-pharyngeal constriction at the level of the second vertebrae between the place of articulation of uvulars and pharyngeals, while a lower pharyngeal constriction below the epiglottis at the level of the fourth and fifth vertebrae is observed in the production of the pharyngeals. Both the tongue root and epiglottis are involved in the production of the pharyngeals /ħ/ and /ʕ/. McCarthy (1994) also indicates that in the pharyngeals, the role of the active articulator is played by both the tongue root and the epiglottis.

However, an endoscopic investigation by Laradi (1983) shows that there is no obvious tongue root involvement in the production of the pharyngeals, but the pharyngeal stricture is formed as high as the epiglottis which is involved in retraction towards the posterior pharyngeal wall. Furthermore, using a fiberscopic observation of the epiglottis during the production of the pharyngeals by a Hebrew speaker, Laufer and Condax (1979) notice the independence of the epiglottis retraction from the tongue root. Another nasoendoscopic study of the pharyngeals in Jordanian Arabic reveals more epiglottal retraction in the pharyngeals than in the pharyngealised consonants, emphasising that Arabic pharyngeals do not involve an articulation between the tongue root and the posterior wall of the pharynx, but it is the tip of the epiglottis and the pharyngeal wall that form the pharyngeal articulations (Heselwood and Al-Tamimi 2006).

Table 2.5 The consonantal system of Libyan Arabic (Laradi 1972, 1983; Abumdas 1985)

manner of articulation	voicing state	place of articulation										
		labio-dental	bilabial	dental/alveolar		inter-dental	post-alveolar	palatal	velar	uvular	pharyngeal	glottal
stop	voiced		b	d	dˤ				g			ʔ
	voiceless			t	tˤ				k	q		
fricative	voiced			z	zˤ	ð, ðˤ	ʒ			ʁ	ʕ	
	voiceless	f		s	sˤ	θ	ʃ			χ	ħ	h
nasal	voiced		m	n								
lateral	voiced			l								
flap	voiced			r								
semi-vowel			w					j				

2.4.4. Summary of articulatory features

Some researchers view emphasis as involving velarisation. This is mostly based on impressionistic observations or on analysis of formant frequency patterns, but not on articulatory studies. Generally speaking, the description offered by articulatory studies locates the secondary articulation in the pharynx. Researchers differ in locating the part of the tongue that makes the narrow constriction in addition to the exact part of the pharynx that is involved: it could be the upper, mid or lower pharynx. There is also articulatory evidence for uvularisation as the articulatory realisation of emphasis. The disagreement among researchers on the exact location of the secondary articulation could also indicate that it is dialect-specific and that it may be caused by variation across speakers. This secondary articulation may or may not cause some other modifications to the vocal tract configuration such as the retraction of the primary articulation, the rounding and protrusion of the lips in addition to possible upward and backward movement of the hyoid bone and rising of the larynx. Generally speaking, the secondary articulation of the emphatic consonants is higher than the primary articulation of the pharyngeals and there is less involvement of the epiglottis in the production of pharyngealised consonants than in that of pharyngeal consonants.

2.5. Acoustic features

A number of acoustic parameters, which may play a role in the plain-emphatic distinction, are discussed. These parameters include formant frequencies and VOT in addition to other durational cues like closure duration of the emphatic stops, the duration of the emphatic segments and adjacent vowels.

2.5.1. Formant frequency patterns

This section examines the effect of emphasis on formant frequency patterns and how this effect is shaped by vowel quality and quantity in addition to speaker variability. The section starts with how the articulation of segments influences their acoustic representation.

2.5.1.1. Articulatory-acoustic relationship

In this section, attention is drawn to the articulatory-acoustic relationship that characterises the emphatics as articulatory information could be predicted from acoustic analysis. For instance, Giannini and Pettorino (1982) observed articulatory and acoustic differences between the emphatic lateral and other emphatics in Iraqi Arabic; these differences were helpful in forming decisions about the emphatic consonants' secondary articulation. The similar F1 pattern for /lˠ/ and /l/ (both laterals have an F1 of 300 Hz) along with their articulatory results showed that /lˠ/ was velarised as assumed by Ferguson (1956) and not pharyngealised as reported by Al-Ani (1970). However, as F1 increased for the emphatic context of /sˤ dˤ tˤ zˤ/, as compared to that of their non-emphatic counterparts; these emphatics were articulatorily found to be pharyngealised.

Acoustic results reported for MSA also led Bin-Muqbil (2006) to conclude that the coronal emphatics behave more like velarised than pharyngealised consonants. This prediction was basically due to the insignificant effect this class of consonant had on F1 of the following vowel. Accordingly, Bin-Muqbil questioned the treatment of emphatics as pharyngealised in the literature. However, it should be noted that the pharyngealisation of the emphatics was based on articulatory evidence (see section 2.4.2.3). The realisation of the secondary articulation of the emphatic consonant could therefore vary depending on the language, dialect or variety.

In fact, the first formant frequency is found to play an important role in locating the back constriction. This has been confirmed by studies on vocal tract modelling, which relate the area functions of the vocal tract to the formant structure (Malmberg 1963; Klatt and Stevens 1969; Lindblom and Sundberg 1971). These studies predict the direct relation between the low location of the pharyngeal constriction and F1 increase.

In a study of vocal tract modelling, a secondary constriction was created from a model of the non-emphatic /s/ by changing the constricted pharyngeal area in a number of steps (Yeou 2001). As the constricted area decreased from 5 cm^2 to 1 cm^2, Yeou observed a drop in F2 and a rise in F1 and F3. Furthermore, Jongman et al's (2007) acoustic analysis of Jordanian Arabic displayed similar results for the first three formants in the emphatic context; therefore it was assumed that this was suggestive of a pharyngeal constriction.

The relation between F3 pattern and the location of the pharyngeal constriction is also reported by Kent and Read (1992) as a lower pharyngeal constriction is associated with high F3. Accordingly, a low-pharyngeal stricture increases F3 while F3 decreases as a function of a mid-pharyngeal constriction, but a constriction in the upper pharynx has no effect or slight increase in F3. Similarly, Lindblom and Sundberg (1971) emphasise F3 increase as a function of moving the tongue from the velar area to the pharyngeal area. Generally speaking, there is an association between a rise in all formant frequencies and a constriction in the lower pharynx (Stevens 2000).

This section seems to indicate that when acoustic results for F1 and F3 vary across different Arabic dialects, this may point to the different realisations of the secondary articulation of the emphatics. F2 pattern does not seem to be as sensitive to locating the posterior constriction as F1 and F3. As F2 is lowered for both velarised and pharyngealised consonants (Giannini and Pettorino 1982), there seems to be a relation between F2 and tongue retraction as also reported earlier by Delattre (1951) regardless of the location of this retraction.

The discussion in this section shows the interface between articulatory and acoustic levels given that articulatory information can be inferred from the acoustic signal (Löfqvist 1990). The physiological changes accompanying the production of the pharyngealised consonants have a range of possible acoustic consequences that have been observed in various Arabic dialects. The pharyngeal constriction caused by the retraction of the tongue towards the pharynx gives the pharyngealised consonants their resonant features that influence adjacent segments (Laradi 1983). This leads to the main perceptual difference between the emphatic and plain consonants.

As the emphatic consonants are reported to have different articulatory correlates, this may result in conflicting formant frequency patterns in the sense that the presence of these articulatory correlates could enhance or counteract the direction of formant frequency movement. For instance, rising of the larynx and the hyoid bone can represent additional articulatory correlates of the emphatic consonants (Laradi 1983; Marçais 1948 as cited in Giannini and Pettorino 1982). Larynx raising reduces the vocal tract length and thus increases the first three formant frequencies (Stevens 2000). On the other hand, Kent and Read (1992) state that F3 and lower formant frequencies are lowered by lip rounding

(rounding enlarges the vocal tract) which can be an additional articulatory correlate of emphasis (see section 2.4.2). The general tendency for emphasis to increase F1 and F3 could be counteracted by lip rounding which may be associated with the production of emphasis. This may lead to difficulty in predicting the articulatory representation of emphasis. Therefore, it may be useful if formant frequency results are supported by articulatory information about the emphatics in a certain dialect.

2.5.1.2. The effect of emphasis on formant frequencies

The effect of emphasis on formant frequency patterns is examined at different points. This examination includes the formant locus, where formant frequencies are measured in the consonant, and formant frequencies at the onset and midpoint of adjacent vowels. A number of researchers have compared the plain with the emphatic realisation in terms of the effect both have on formant loci (see Table 2.6). For instance, F2 locus for the emphatic consonants has been reported to be considerably lower than F2 locus for the plain consonants in Lebanese Arabic (Obrecht 1968), Iraqi Arabic (Odisho 1973) and Moroccan Arabic (Yeou 1997). F2 locus therefore plays an important role in the plain-emphatic distinction.

Table 2.6. F2 locus for three Arabic dialects

Obrecht (1968) Lebanese Arabic		Yeou (1997) Moroccan Arabic		Odisho (1973) Iraqi Arabic			
plain	emphatic	plain	emphatic	/t/	/tˤ/	/d/	/dˤ/
1800	1200	1625-1844	996-1192	1800	1100	1700	1100

Other researchers like Giannini and Pettorino (1982) have explored both F1 and F2 loci in the plain-emphatic distinction. Their findings suggest higher F1 and lower F2 loci for the emphatic consonants as compared to their plain counterparts; F1 and F2 loci are 600 and 1000 Hz for the emphatic consonants, while they are 250 and 2000 Hz for the non-emphatic consonants respectively. It is clear that both F1 and F2 loci are crucial in the distinction between the two classes due to the large F1 and F2 differences between the plain and emphatic contexts.

The increase in F1 and decrease in F2 is also consistently reported in most studies in which these formant frequencies are measured for the adjacent vowels in the emphatic environment: Al-Ani (1970) on Iraqi Arabic; Rajouni et al (1987) and Yeou (2001) on Moroccan Arabic; Norlin (1987) on Egyptian Arabic; Al-Bannai (2000) on different dialects of Arabic; Kriba (2004) on Libyan Arabic; Kuriyagawa et al (1988), Al-Masri and Jongman (2004) and Khattab et al (2006) on Jordanian Arabic; Bukshaisha (1985) on Qatari Arabic; Hussain (1985) on Gulf Arabic; Ghazali (1977) on different Arabic dialects among others. In fact, the influence of emphasis is evident at vowel onset, the closest measuring point to the emphatic consonants. For instance, an acoustic investigation carried out by Bukshaisha (1985) for Qatari Arabic (QA) showed that F2 at the onset of different vowels decreased considerably in the emphatic as compared to the plain environment (see Table 2.7).

Table 2.7. Mean F2 onset in the emphatic and plain contexts in QA (Bukshaisha 1985)

vowel	/s/	/sˤ/	/t/	/tˤ/	/ð/	/ðˤ/
/i/	1700	1025	1850	1100	1750	1100
/i:/	2000	1000	2250	1100	1850	1000
/e:/	1850	1000	2000	1025	-	1100
/a/	1750	1150	1700	1100	1500	1100
/a:/	1500	1100	1300	1100	1400	1000
/u/	-	1000	1500	1000	-	-
/o:/	1400	1000	1500	1075	-	-
/u:/	1500	750	1450	750	1500	750

On the other hand, the effect of emphasis was found to decrease at the midpoint or steady state of the vowel as the measuring point distances from the emphatic consonants (Hussain 1985; Jongman et al 2007). For example, Hussain's (1985) results for Gulf Arabic (GA) allows one to track the decreasing effect of emphasis on F2 since it is more considerable on the onset than on the steady state (see Table 2.8). This effect could vary depending on the vocalic context as discussed later in this section.

Table 2.8 Mean F2 in the emphatic and plain context in GA (Hussain 1985)

	F2 onset						F2 steady state					
vowel	/t/	/tˤ/	/ð/	/ðˤ/	/s/	/sˤ/	/t/	/tˤ/	/ð/	/ðˤ/	/s/	/sˤ/
/i/	1926	1245	1976	1260	1826	1210	2094	1490	2260	1577	2173	1479
/a/	1670	874	1577	1195	1457	1082	1647	986	1663	1170	1611	1195
/u/	841	853	836	845	817	839	896	860	879	859	880	846
/i:/	2158	1245	2075	1245	1992	996	2426	2400	2407	2420	2407	2396
/a:/	1328	913	1062	920	1626	992	1245	996	1306	1079	1404	1062
/u:/	779	794	789	782	714	742	846	816	849	807	798	765
/e:/	1826	950	1660	830	1826	747	2324	2020	2241	1992	2253	2075
/o:/	830	816	856	829	826	795	965	847	920	859	945	830

It is noted that F2 lowering is more important than F1 rising in the production of the emphatic consonants (Watson 2002; Hassan 2005). This could be the reason why some researchers (e.g., Obrecht, 1968 on Lebanese; A-Masri and Jongman 2004 on Jordanian among others) consider only F2 in their studies of emphasis. Some researchers observed an insignificant effect of emphasis on F1 in Palestinian Arabic (Card 1983), in Egyptian Arabic (Norlin 1987) and in MSA (Bin-Muqbil 2006). Other researchers (e.g., Yeou 2001; Khattab et al 2006) reported the significant effect of emphasis on F1 increase. This shows dialectal variation in the effect of emphasis on F1. This cross dialectal variation for F1 could suggest different articulatory manifestations of the secondary articulation (see section 2.5.1.1). Although acoustic evidence may suggest that the effect of emphasis on F2 of adjacent vowels is greater than that of F1, the role of F1 in the identification of the emphatic consonants can not be played down on this basis.

Generally speaking, for the emphatic consonants, backing is manifested in F1 increase and F2 decrease, with F2 decrease being more extensive than F1 increase (Ghazali 1977). The first two formant frequencies play a major role in shaping vowel quality (Peterson 1951) and can function as sufficient acoustic cues in the perceptual identification of vowels (Strange 1989). Kent and Read (1992) indicate that tongue height is correlated with F1 and tongue backing with F2; as the tongue moves from a high to a low position F1 increases and from a front to a back position F2 decreases. Emphasis mainly leads to a decrease in F2 due to the enlargement of the oral cavity and an increase in F1 due to the decrease of the volume of the pharyngeal cavity (Watson 2002). Thus F1 and F2 approach each other in the emphatic context (Odisho 1973; Giannini and Pettorino 1982), producing a more compact spectrum than that in the plain context (Ghazali 1977). Fant (1970) also emphasises the role of F1-F2 difference as a crucial cue for determining the feature [retraction].

Results from most studies on Arabic suggest that F3 is the least affected formant frequency compared to lower formant frequencies, as F1 and F2 are thought to offer more reliable evidence for the plain-emphatic opposition than F3 (Al-Nuzaili 1993). Al-Ani and El-Dalee (1983) comment on the distance between formant frequencies in characterising the feature [retraction], indicating that the F1-F2 difference is more important than the F2-F3 difference. The role of F3 in the plain-emphatic distinction is played down in Iraqi Arabic (Giannini and Pettorino 1982), Egyptian Arabic (Al-Ani and El-Dalee 1983), Yemeni Arabic (Al-Nuzaili 1993) and Jordanian Arabic (Khattab et al 2006). These researchers use terms like "inconsistent", "unclear", "unchanged", "fluctuating" and "similar" to express the unreliable effect of emphasis on F3.

Although F3 pattern does not seem to be reliable in the plain-emphatic distinction in most Arabic dialect, it is observed in Norlin's (1987) results that the effect of emphasis on F3 depends on the vocalic context in Egyptian Arabic. In Egyptian Arabic, F3 onset and steady state increase considerably in the emphatic context for /u:/ and /o:/ while it increases slightly for /u a: a/. On the other hand, F3 onset and steady state is considerably higher for /i:/ in the plain context than in the emphatic one and the same result is found for /ɪ/, but the increase is very slight. In the /e:/ context, emphasis leads to F3 onset increase and F3 steady state decrease.

Similarly, results from Libyan Arabic have shown that the increasing effect of emphasis on F3 onset was evident for the back vowel /u:/ compared to /a:/ and /i:/ (Kriba 2004). Results from Jordanian Arabic show that emphasis leads to an F3 increase in the context of /i: i æ: æ u: u/ (Jongman et al 2007). This F3 increase is attributed to the pharyngeal constriction. This is supported by results from vocal tract modelling studies (see section 2.5.1.1).

The effect of emphasis on vowel formant frequencies shows that there are consonant-to-vowel coarticulatory effects. According to endoscopic observation, the tongue keeps the configuration needed for the production of the emphatic consonants during the articulation of an adjacent vowel and is still in it at the start of a following vowel (Laufer and Baer 1988). Hussain (1985) and Ali and Daniloff (1972b) also state that the tongue retraction for the emphatic consonants is superimposed on the articulation of adjacent vowels.

Therefore, the vowel in the emphatic context is retracted and lowered as compared to the same vowel in the non-emphatic context (Giannini and Pettorino 1982; Hetzron 1997). The quality of each vowel is dark in the emphatic syllable and clear in the plain syllable (Paddock 1970). But the coarticulatory effect of emphasis on adjacent vowels depends on vowel quality. The influence of speech sounds on adjacent segments varies, depending on the articulatory configuration difference between adjacent segments; this effect increases as the difference increases (Rosner and Pickering 1994; Recasens 1999; Recasens et al 1998). So compatibility between the articulations of adjacent segments reduces the effect of these segments on one another and increase coarticulation between them (see section 2.7.1 for more details on coarticulation and coarticulatory resistance).

Emphasis is found to considerably affect the onset of high front long vowels like /i:/ and/or /e:/, causing a large rising transition as reported by Ghazali (1977) for a variety of Arabic dialects, Younes (1982) and Card (1983) for Palestinian Arabic and Bukshaisha (1985) for Qatari Arabic. The spectrographic analysis carried out by Bukshaisha (1985) shows that in the vicinity of an emphatic consonant the long rising F2 transition duration for /i:/ and /e:/ represents about one third of the total vowel duration before these vowels reach their steady state values at 2000- 2250 Hz for /i:/ and 1850-2000 Hz for /e:/.

Articulatory justifications are provided for the long transition found for /i:/ and /e:/ in the emphatic context. In the articulation of these high front vowels, the tongue back gradually takes up the position necessary for achieving the target position for these vowels; therefore, the mass of the tongue takes a longer time to approach the steady state of these vowels (Ghazali 1977). Likewise, Bukshaisha (1985) indicates that while the tongue tip or blade moves quickly, the secondary gesture remains in place while the vowel is produced, causing low F2 onset. In fact, the tongue tip is capable of achieving the quickest movement compared to other articulators (Hudgins and Stetson 1937). As the secondary articulation disappears gradually and the vowel achieves its articulatory configuration, F2 increases due to the enlarged pharyngeal cavity and the decreased volume of the oral cavity that is responsible for F2 resonance (Bukshaisha 1985). This in turn enables these vowels to approximate their target values and display more stable and resistant articulatory features. The long transition for /i:/ and /e:/ represents the degree of required movement of the tongue from the emphatic to the vowel position and how fast that movement is.

The effect of emphasis is more extensive on the onset of high front long vowels than on their steady state. This could be the reason why Hussain (1985) and Card (1983) note that the vowel /i:/ in Gulf and Palestinian Arabic is not backed when adjacent to an emphatic consonant as the coarticulatory effect of emphasis is greater on the F2 transition than on the central part of /i:/. Furthermore, Laradi's (1983) articulatory analysis of Libyan Arabic shows that in the production of /tˤ/ in /tˤi:n/, there is slight retraction of the tongue as high as the second cervical vertebrae. This suggests that the tongue is not fully backed when the emphatic consonant is produced in the context of /i:/.

The degree of transition seems to decrease as the vowel moves from front to back since back vowels like [u:] lack F2 transition in the emphatic environment (Ghazali 1977; Younes 1982; Bukshaisha 1985). The lack of transition in /u:/ in the emphatic context is attributable to the compatibility between the articulation of this back vowel and the emphatic articulation (Card 1983). Bukshaisha (1985) notes that the back vowels /u: u o:/ exhibit no transition in the emphatic environment whereas they have a falling transition in the plain environment. This is because in the plain context, F2 starts at a high value at vowel onset due to a coronal articulation and decreases as these vowels reach their steady state. This F2 decrease, according to Bukshaisha (1985), is due to the retraction of the tongue during the production of back vowels.

While the vowels discussed so far exhibit various degrees of acoustic effects in the emphatic environment, but retain their identity in terms of the broad phonetic category that they belong to, the low vowel /a(:)/ undergoes more major changes. Unlike other vowels, the whole duration of the vowel /a(:)/ is affected in the emphatic context so it is realised as a back vowel [ɑ(:)] (Paddock 1970; Ghazali 1977; Bukshaisha 1985; Hussain 1985). This is due to the fact that low vowels display a similar pharyngealisation effect at the onset and steady state (Yeou 1997). As a result, the low vowel has two allophones, namely a front [a(:)] or [æ(:)] in the plain context and a back [ɑ(:)] in the emphatic context as also confirmed by Haddad (1984) for Lebanese Arabic, Card (1983) for Palestinian Arabic, Hussain (1985) for Gulf Arabic; Bukshaisha (1985) for Qatari Arabic among others.

The articulation of the low vowel [ɑ(:)] shows compatibility with the pharyngeal articulation (Yeou 2001). This compatibility lies in the fact that both are produced with a similar pharyngeal constriction (Delattre 1971; Laradi 1983; Al-Ani and El-Dalee 1983). Thus the volume of the oral cavity is wider for the low vowels than that of other vowels (El-Dalee 1984).

This section has shown that the effect of emphasis on formant frequency patterns leads to an increase in F1 and F3, and a decrease in F2. This effect is more pronounced in F2 followed by F1 while the F3 pattern is not consistent in most Arabic dialects.

2.5.1.3. The effect of vowel duration on formant frequencies

The effect of emphasis is found to be dependent on vowel duration. In the emphatic context, short vowels are observed to display greater change in formant frequency patterns than that observed for long vowels (Norlin 1987; Rajouni et al 1987). The degree of formant undershoot therefore depends on vowel duration; the shorter the vowel, the greater the undershoot (Lindblom 1963b; Engstrand and Krull 1988, 1989). Therefore, long vowels regain their target configuration due to their longer duration while short vowels never reach their steady state (Strange 1989).

In the emphatic context the long /iː/ reaches its steady state as a result of its long duration whereas the short /i/ never reaches its steady state due to its short duration (Hussain 1985; Bukshaisha 1985). Hussain (1985) indicates that for many cases, short /i/ has no steady state, but exhibits only a rising F2 transition. The fact that the short /i/ does not reach its steady state in the emphatic context is reflected in the F2 difference between plain and emphatic contexts. Hussain (1985) notes a considerable F2 difference between /i/ in plain and emphatic contexts whereas the F2 difference is small between the two contexts in the case of /iː/. Bukshaisha (1985) confirms that the short /i/ can have a rising F2 transition with no steady state in the emphatic context, but in the majority of cases there is no F2 transition and F2 is lowered throughout the whole vowel. This is also an indication of the short /i/ being incapable of reaching its steady state.

The considerable effect of emphasis on the short /i/ explains why it is realised as [ɨ] in the emphatic context, leading to a vowel similar to schwa (Bukshaisha 1985; Hussain 1985). In the case of the short vowel, emphasis spreads to cover the whole vowel, but this is not true for the long one (Card 1983; Norlin 1987 among others). This is because of different coarticulatory effects on these vowels. There is sufficient time for the coarticulatory effect of the emphatic consonant on a long vowel to decrease, so the vowel can approach formant frequency values found in the plain context while this coarticulatory effect does not diminish for short vowels (Norlin 1987).

A phonological interpretation by Giannini and Pettorino (1982) ascribes this acoustic difference between short and long vowels to the different roles they have in the phonological system of Arabic: long vowels are viewed as having a function similar to that of the consonants whereas the short ones represent a kind of "harakat" (movement) from one consonant to another. As a result, short vowels have less stability in their articulation than the long ones and are more likely to be influenced by the environment.

2.5.1.4. Speaker variability

Speakers from the same dialect could vary their articulatory realisation of the plain and emphatic consonants consequently yielding various acoustic effects. Khattab et al (2006) report that in the achievement of /t/-/ṭ/ distinction, speakers show a diversity in the degree of both tongue backing in the production of the emphatic /ṭ/ and tongue fronting in the production of the plain /t/. Yeou (2001) attributed the variability in the production of vowels in the emphatic context to differences in the size of the vocal tract; however, F1 increase and F2 decrease still exhibit a consistent pattern. In fact, variability in speech production has been documented in the literature (e.g., Peterson and Barney 1952; Perkell 1990; Al-Tamimi and Barkat-Defradas 2002).

The production of the emphatic consonants is controlled by other vocal tract activities that could affect formant frequencies such as the rounding and protrusion of the lips (Lehn 1968) in addition to possible larynx raising (Laradi 1983), not just the back tongue movement. Therefore, speakers can employ a range of articulatory strategies and may manipulate these articulatory correlates of emphasis differently, leading to acoustic variation as far as formant frequencies are concerned. This is because the different articulatory correlates of emphasis yield different acoustic results (see section 2.5.1.1).

The magnitude of formant undershoot could depend on factors related to the consonantal type, the surrounding vowel, idiosyncratic patterns, speaking rate, vocal tract size, dialect, socio-economic factors, emotional state and/or the social context among others (Lindblom 1963b; Rosner and Pickering 1994; Pisoni and Lively 1995; Ryalls 1996; Frieda et al 2000). These factors cause inter- and intra-speaker variability, which is typically represented graphically in F1/F2 plots (e.g., Disner 1986). Formant frequency plots normally show an overlap between vowels in the pharyngealised context and vowels in the non-pharyngealised context in addition to variation for both contexts (e.g., Al-Ani 1970).

The varying effect of the consonantal type on formant undershoot has been reported by Bin-Muqbil (2006), whose study shows that the emphatic context of /tˤ dˤ ðˤ/ has a statistically insignificant F2 difference, while F2 for /sˁ/ is significantly higher than that of the emphatics /tˁ dˁ ðˁ/. This could be caused by different degrees of tongue backing which, according to Ghazali (1977), is greater for the emphatic /tˁ/ than for /sˁ/. Furthermore, Laufer and Baer (1988) indicate that the degree of narrowing of the pharyngeal constriction depends on the emphatic type and vocalic context; for instance it is narrower for /tˁ/ than for /sˁ/ and narrower for /a/ than for /i/.

Speaker variability can be manifest in the acoustic results, but not in the auditory impression of vowels. The way listeners process a large set of acoustic events as the same auditory event may be due to expectation and phonology. According to Lindblom's (1990) H and H theory which points to hyper- and hypo-articulation, listeners focus on the message and the meaning of the target word with which they are presented; in this case they apply top-down processes to the listening task and ignore certain acoustic differences (Lindblom 1990). A listener may also resort to categorical labelling and ignore context-related information in the auditory processes (Carney et al 1977; Pisoni and Tash 1974).

Moreover, Joos (1948) explains the acoustic variation in the production of vowels, which are not auditorily perceived by stating that the vowel space is classified into templates or zones and the vocalic elements that occupy a certain zone are recognised as the same vowel. Joos (1948) suggests that on hearing an utterance, listeners create a reference vowel form that they employ to locate new similar vowels in the process of hearing them. To achieve this, listeners depend on information associated with speech context and visual information related to the speakers, which they use for determining the size of their vocal tract.

The concept of "perceptual magnet" suggested by Kuhl (1991) could also provide explanation for the acoustic variability across speakers in a situation where listeners are able to distinguish between vowels belonging to different categories but not those related to the same category. In this case, a prototype of a vowel category functions as a perceptual magnet that draws other members of the category which exhibit similarity with it and they are therefore difficult to distinguish by the listeners while they distinguish those sounds that are distant from the prototype. Kuhl (2000) suggests that humans are naturally born with an ability to discriminate all universal sounds, but this ability declines gradually, and disappears after the first year of age when the production of vowels become tightened around prototypes of vowels in their native language (Kuhl et al 1992).

Although the acoustic study of vowels of the Libyan dialect of Rayaina signals the presence of inter- and intra-speaker variation within the same vowel and across different vowels (Ahmed 2008), this acoustic variation does not correspond with Ahmed's auditory results in which he made use of much fewer categories to classify the vowel phonemes. So a vowel could be acoustically variable across speakers, but still be perceived as belonging to the same category when it comes to identification on the part of the listener (Peterson and Barney, 1952). It may also be the case that Ahmed (2008) did not make use of fine phonetic transcription when he analysed the vowels in his study, which may have shown more gradient variation. Generally speaking vowel perception is found to be continuous compared to the perception of the consonants which shows a tendency towards being categorical (e.g., Liberman et al 1957; Fry et al 1962; Abramson and Lisker 1967; Pisoni 1973; Repp et al 1979).

The categorical perception of consonants was discussed by some researchers. For instance, Liberman et al (1957) varied F2 transition in a number of 14 steps to generate the range of the continuum necessary for producing the stops /b d g/. In an identification task, listeners were presented with randomised stimuli, and asked to identify each stimulus as /b/ /d/ or /g/ . In a discrimination task, listeners were asked to classify X as A or B from triads of stimuli (ABX). Participants succeeded in categorising the three consonants in both tasks. This presented evidence for the discontinuity of the perception of the consonant.

However, vowels showed a tendency towards continuous perception as no definite boundary can be drawn between stimuli on a continuum that ranges from one vowel to another. For instance, Fry et al (1962) examined vowel perception through the use of a vowel continuum of 13 stimuli, ranging from /ɪ/ to /ɛ/ to /æ/. The first two formant frequencies were controlled in the generation of this continuum. First, in an identification task, listeners were asked to identify each of these three vowels. A forced-choice technique was adopted in a discrimination task in which triads of ABC were presented to listeners (A and B were always different and X was the same as either A or B). The participants were expected to indicate which two of these three stimuli were the same and which one was different.

Both the identification and discrimination tasks showed that participants reached various decisions in allocating the stimuli to this or that vowel category as they perceived stimuli at the middle of the continuum (Fry et al 1962). The continuity of vowel perception caused a confusing situation as the acoustic cues at the middle of the continuum were inadequate to label the stimuli as belonging to this or that vowel. The acoustic cues at the middle of the continua are not representative of the vowels at the endpoints which represent the best prototypes of the vowels. (A and B were always different and X was identical to either A or B).

The perception of the consonant, unlike the perception of the vowel, showed a clear-cut boundary between different consonants (Liberman et al 1957; Fry et al 1962). The results of these studies had implications for the articulatory differences between consonants and vowels. The production of a consonant is characterised by having discrete articulatory targets as there is discontinuity between the articulations of different consonants whereas the production of vowels involves articulatory continuity.

2.5.2. The effect of emphasis on voice onset time

Temporal relations between consonants and vowels are influenced by emphasis. One of the most common durational parameters that have shown to vary between plain and emphatic contexts is voice onset time (VOT). VOT is conventionally defined by Lisker and Abramson (1964) as the relation in time between the release burst of a stop and the start of voicing. According to Lisker and Abramson (1964), three categories determine the relation in time between the release of the stop closure and the start of voicing:

1. voicing can start just before the release of a stop closure and this is known as "voicing lead"

2. voicing may start just after the release of the closure and this is known as "short lag"

3. there may be a considerable delay of voicing after the release of the closure and this is known as "long lag".

If voicing starts before the stop release, VOT would have a negative value and if it starts after the release, VOT would have a positive value (Lisker and Abramson 1964; Keating 1984). A VOT range from 20-25 constitutes a short lag and higher VOT values than this form a long lag (Keating 1984). VOT was given a zero value when voicing coincides with the release of the stop (Swartz 1992). Laver (1994) indicates that aspiration may be called voice delay. Therefore, the two terms could be used interchangeably. A VOT value longer than 25-30 ms causes audible aspiration noise that occupies the time interval between the stop burst and the onset of voicing (Laver 1994).

Most studies on VOT have found that the voiceless emphatic stops can be distinguished from their non-emphatic counterparts by means of the timing of voicing following the release of the stop. The general pattern for the vocal folds is to start vibrating earlier in the case of a vowel occurring after the emphatic /ṭ/ than in the case of a vowel following /t/ (e.g., Ghazali 1977; Al-Nuzaili 1993; Kriba 2004; Khattab et 2006). Ghazali (1977) found a VOT of 30 ms for the plain /t/ and 10 or 15 ms for the emphatic /ṭ/ in initial position; he attributed this durational difference to the presence of aspiration in /t/ and its absence in /ṭ/. Similarly, Khattab et al's (2006) male speakers of Jordanian Arabic produced a non-aspirated /ṭ/ (VOT=18 ms) and an aspirated /t/ (VOT=37 ms). The VOT results offered by Bukshaisha (1985) for male adult native speakers of Qatari Arabic show that the plain /t/ was aspirated while the emphatic /ṭ/ was unaspirated and that there is no overlap between the contrast (VOT for /ṭ/ ranged from 0 to 15 ms and from 30 to 50 ms for /t/).

Another study on emphasis and voicing in Yemeni Arabic (YA), where Al-Nuzaili (1993) introduces himself as the only subject, shows that emphasis has the effect of decreasing VOT in the case of the voiceless plosives (see Table 2.9). In Al-Nuzaili's (1993) study the range for the VOT value for /t/ was from 15 to 55 ms and from -30 to 25 ms for /ṭ/. This exhibited some overlap between the values for /t/ and /ṭ/, however, the mean values show that VOT could distinguish /t/ from /ṭ/. It was also interesting to note that the emphatic /ṭ/ could sometimes show a tendency towards prevoicing (see Table 2.9).

Table 2.9. Mean and range for VOT for /ṭ/ and /t/ in YA (Al-Nuzaili 1993)

stop	value	/a:/	/u:/	/i:/	/a/	/u/	/i/	overall range
/t/	mean	21.67	41.67	50	22	33.33	37.50	
	range	20-25	35-50	40-55	15-35	20-40	30-40	15-55
/ṭ/	mean	10.83	11.67	9.17	8.33	10	9.50	
	range	5-20	5-20	-30-25	0-10	0-15	0-20	-30-25

A study on Libyan Arabic showed that /t/ had a longer VOT than /ṭ/ as the average VOT values for /t/ and /ṭ/ produced by one Libyan speaker were about 44 and 33 ms respectively (Kriba 2004). Therefore, in Libyan Arabic /ṭ/ was slightly aspirated and /t/ was aspirated. This is true for all vocalic contexts investigated (see Table 2.10), but in the context of the high front vowel, /ṭ/ can have stronger aspiration than in the other vocalic contexts. The possibility for the voiceless non-emphatic plosive to be aspirated in Tripoli Libyan Arabic is also referred to by Laradi (1983).

Table 2.10. Mean VOT values for /t/ and /ṭ/in LA (Kriba 2004)

stop	/i:/	/a:/	/u:/
/t/	50	30	51
/ṭ/	43.6	24.6	30

Results from some Arabic dialects show that VOT does not always lead to the /t/-/ṭ/ distinction. Heselwood (1996) found that the mean VOT values for /t/ and /ṭ/ preceding /a:/ as produced by Iraqi speakers were 31 ms and 16 ms respectively. However, his Egyptian speakers produced both stops with slight aspiration; the mean VOT for /t/ was 33 ms and 35 ms for /ṭ/. The slight aspiration for /t/ and /ṭ/ in Egyptian Arabic was also observed by Shaheen (1979) in which aspiration lasted for about 30 ms, and by Rifaat (2003) who reported no significant difference in the VOT values of the Egyptian /t/ and /ṭ/.

Furthermore, Sudanese Arabic presented completely different results from those reported for other Arabic dialects by exhibiting significantly longer VOT for /ṭ/ than for /t/; VOT ranged between 30 to 70 ms for the plain /t/ and 40 to 90 ms for the emphatic /ṭ/ (Ahmed 1984). This is contrary to the results mentioned above which reveal that the plain /t/ is more aspirated than its emphatic counterpart /ṭ/ which is either slightly aspirated or has no aspiration at all. Sudanese Arabic exhibits overlap in the VOT values for the plain and emphatic contexts and this overlap is expected by Ahmed (1984) because of the similarity between the two consonants in most respects with the exception of the feature "emphasis".

Results from Egyptian and Sudanese Arabic seem to point to the importance of looking at the role of the dialect in the realisation of VOT in the /t/-/ṭ/ contrast, indicating that the effect of emphasis on VOT decrease can not be taken for granted as a universal principle that one would trace in all dialects. This is particularly true for Egyptian Arabic given that the slight effect of emphasis on VOT is consistent across different studies as reported by Shaheen (1979), Heselwood (1996) and Rifaat (2003). However, as Ahmed (Ahmed 1984) used only two male speakers of Sudanese Arabic, his results may not reflect the VOT pattern in Sudanese Arabic especially if taking into consideration that Sudanese Arabic deviates from the tendency observed in other dialects as far as the decreasing effect of emphasis on VOT is concerned.

The effect of emphasis on VOT for the voiceless stops is not observed in the case of the voiced stops. Concerning the voiced plain /d/ and its emphatic counterpart, there is more agreement cross-dialectally on VOT for /d/ and /ḍ/ than that for the voiceless plain /t/ and emphatic /ṭ/. An investigation of VOT in some Arabic dialects shows that both voiced stops are associated with voicing lead (e.g., Yeni-Komshian et al. 1977; Al-Nuzaili 1993; Rifaat 2003; Kriba 2004).

VOT values also varied depending on the vocalic context (Lisker and Abramson 1967; Port and Rotunna 1979). For instance, VOT is longer before high vowels than before mid or low vowels (Klatt 1975; Alghamdi 1990; Docherty 1992). The voiceless stop /ṭ/ is associated with longer lags before high front /i iː/ than before low /a aː/ and high back /u uː/ in Lebanese Arabic (Yeni-Komshian et. al 1977), Yemeni Arabic (Al-Nuzaili 1993) and Libyan Arabic (Kriba 2004).

At this point, it is worth investigating potential factors behind the decreasing VOT for /ṭ/ in the emphatic context. Explanation of such factors is based on mechanisms related to different voicing patterns for the contrast as a function of the secondary articulation. The different timing of voicing in the context of /ṭ/ and /t/ lend credence to the view that the lower VOT values for /ṭ/ than /t/ results from a narrower glottal opening caused by the presence of the secondary constriction in the back of the vocal tract.

Al-Halees (2003) found correspondence between the degree of glottal opening, using fiberoptic evidence, and VOT results for /ṭ/ (16 ms) and /t/ (35 ms) following /i/ in Jordanian Arabic. The emphatic /ṭ/ exhibited a small glottal opening compared to the plain /t/. Similar results are confirmed by a fiberscopic study of Moroccan Arabic in which Zeroual (1999) observed more glottal opening for /t/ than /ṭ/ before and during the release phase of the stop. This would let more air out in the production of /t/, causing more aspiration and higher VOT values for /t/ than for /ṭ/. According to Al-Nuzaili (1993), the release of /ṭ/ is accompanied by a lower peak oral airflow than that of /t/, which is attributable to the pharyngeal constriction. Zeroual (1999) further found that the mean VOT values for /t/ and /ṭ/ preceding the vowels /a/ and /i/ are 63 and 24 ms respectively, lending acoustic support to the articulatory results. The positive correlation between aspiration and glottal opening is also reported by Kim (1970) who states that the more open the glottis during aspiration, the greater the aspiration is. Similarly, later studies have confirmed this tendency in Japanese (Sawashima and Miyazaki 1973), Korean (Kagaya 1974) Icelandic (Pétursson 1976) and Danish (Hutters 1985).

However, the results in the literature concerning the relation between glottal opening and oral release may not always account for the difference between aspirated and unaspirated stops. Results presented by Ridouane (2003) for Berber shows that both singleton and geminate stops are aspirated although geminates display larger glottal opening than singletons. But instead of looking at the overall size of glottal opening, Ridouane's (2003) results show that the degree of glottal opening at the oral release is actually similar for singleton and geminate stops, suggesting that in order to explore the relation between aspiration and glottal opening, focus should be on the peak glottal opening at the point of stop release.

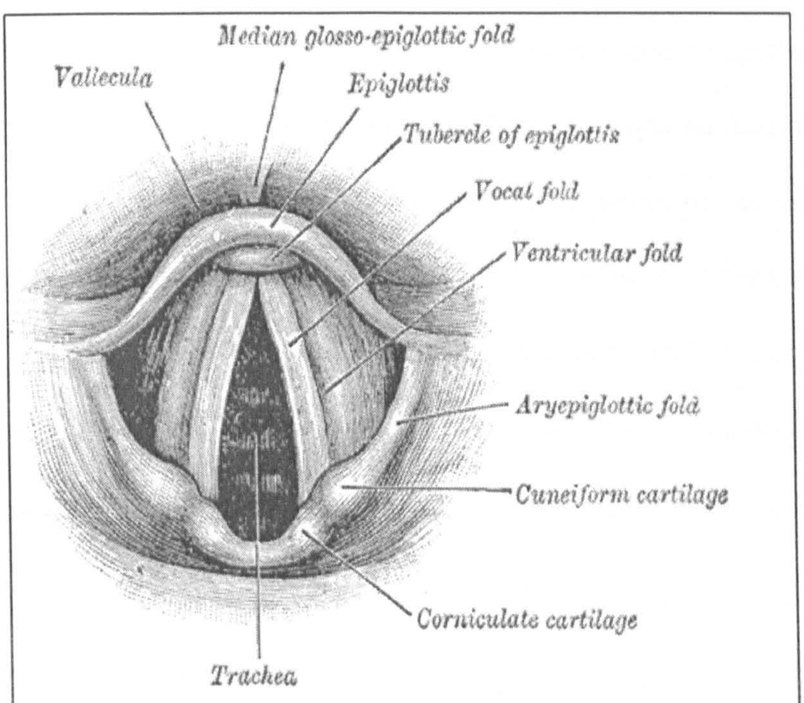
In fact, the timing between laryngeal and oral activities plays a more important role than the size of glottal opening in the distinction between aspirated and unaspirated stops (Löfqvist 1980, 1992; Al-Bamerni and Bladon 1981; Hutters 1985). For instance, Hutters's (1985) survey of stops in different languages shows that in the languages which have longer aspiration, the explosion occurs slightly before or simultaneous with the maximum glottal opening whereas in other languages with shorter aspiration, explosion occurs after this maximum. Hutters (1985) notes that for the aspirated stops the oral release happens close to the moment of maximum opening, preceding the peak glottal opening by around 20 ms while for the unaspirated stops, the timing of this maximum precedes the stop release by around 50 ms.

The above results point to the importance of examining the timing between the laryngeal and oral activities in order to explain the variation in the acoustic realisation of VOT between /t/ and /ṭ/ in different Arabic dialects.

As the voiceless stops can be either aspirated or unaspirated, depending on the degree of glottal opening, it is necessary to distinguish between these two phonation types. Aspirated voiceless stops are produced with breathy voice while the non-aspirated voiceless stops are classified as "pre-phonation" which differs from other states of the glottis like breath (Harris 1999). Pre-phonation state of the glottis is similar to that found in modal voice; however, the glottis is narrower for pre-phonation than for modal voice (Esling and Harris 2003; Esling and Harris 2005).

The question to be raised concerns the effect of the pharyngeal constriction, accompanying the emphatic consonants on glottal activities. This effect is explained by Esling et al's (2005) model which shows that articulations at the glottal level are influenced by a constriction at the supraglottic level. In fact, the pharyngeal constriction is also shaped by "the laryngeal constrictor mechanism" which is accountable for the state of the glottis and the surrounding aryepiglottic folds (Esling 2005). It should be noted that Esling's description is based on pharyngeal sounds rather than pharyngealised sounds. However, since Esling's model relates the laryngeal activities to the pharyngeal constriction and the production of the emphatic consonant involves a pharyngeal constriction, this model could explain why emphasis is associated with narrowing the glottis as reported earlier in this section. Esling's (1996) laryngoscopic investigation confirms the involvement of a constriction of the aryepiglottic folds during a pharyngeal stricture which is formed as a function of tongue root retraction. According to Esling (1999), the pharyngeal constriction is associated with the approximation of the cuneiform cartilages in the direction of the epiglottis base. Esling and Harris (2003) also highlight the importance of adjusting the cuneiform tubercles from a posterior to an anterior manner in squeezing the ventricular folds during a pharyngeal stricture. This all suggests that the pharyngeal constriction affects the muscles in and surrounding the glottal area (see Figure 2.1), leading to narrowing the glottis and explaining why the emphatic (pharyngealised) consonants exhibit narrower glottal opening and accordingly shorter VOT than their plain counterparts.

Fig. 2.1. The glottis and the surrounding tissues[2]



[2] http://en.wikipedia.org/wiki/File:Gray956.png [accessed on the 31.08.2009].

2.5.3. The effect of emphasis on the duration of segments

This section surveys the effect of emphasis on duration given that the emphatic consonants and/or the adjacent vowels may be longer than their plain counterparts. The complexity of the articulation of the emphatic consonant often motivates assumptions about the longer duration of the emphatic as compared to the plain consonant as a function of the greater intensity of the emphatic consonants as discussed later in this section. Chomsky and Halle (1968) also confirm that in the articulation of tense sounds, whether vowels or consonants, the articulators maintain their configuration for longer duration compared to that of lax articulations. The production of tense sounds, according to Chomsky and Halle (1968), requires exerting a greater articulatory effort than that of lax sounds; the great articulatory effort is caused by a considerable tension of the muscles which control the configuration of the vocal tract.

According to Ali and Daniloff (1972a), the secondary articulation of the emphatic consonant is accomplished by tongue retraction, depression of the tongue body and pharynx tension. They also state that the term "emphatic" is a translated form for the Arabic word "mufaxxama" which is related to distinctive features, one of which is tense. Bukshaisha (1985) also refers to the emphatic consonants as tense articulations and notes that the longer duration for vowels in the emphatic context can therefore be attributed to physiological factors related to the secondary articulation of the emphatics. Bukshaisha (1985) also reported the longer duration for /sˤ/ than /s/, regarding it as an indication of greater intensity for the former and so did Kuriyagawa et al (1988) for standard Arabic (SA) produced by Jordanian speakers (see Table 2.11).

Table 2.11. Duration of the Standard Arabic /s/ and /sˤ/ (Kuriyagawa et al 1988)

word	target	duration
/si:b/	/s/	154
/sˤi:b/	/sˤ/	170
/si:ħ/	/s/	146
/sˤi:ħ/	/sˤ/	166

Other researchers, on the other hand, reported no significant durational difference between the emphatic and the non-emphatic consonants in Iraqi Arabic (Ali and Daniloff 1972b), Gulf Arabic (Hussain 1985), Egyptian Arabic (El-Dalee 1984), and Jordanian Arabic (Al-Masri and Jongman 2004) and various Arabic dialects (Al-Bannai 2000). Contradictory observations were reported by Giannini and Pettorino (1982) for the duration of the emphatic-non-emphatic contrast in Iraqi Arabic; in the opposition /sara/-/sˤara/, the emphatic /sˤ/ was longer than the non-emphatic /s/ whereas in the /si:n/-/sˤi:n/ opposition, /s/ was longer than /sˤ/. The inconsistent pattern found in the duration of the emphatic consonants cross-dialectally and sometimes within the same dialect does not provide a clear picture that reflects the effect of emphasis on the duration of segments.

The effect of emphasis is also observed on closure duration (CD) of the emphatic stops. It was reported that the emphatic /tˤ/ had longer closure duration than the plain /t/ in Gulf Arabic (Bukshaisha 1985) and Yemeni spoken Arabic (Al-Nuzaili 1993). Bukshaisha (1985) attributes the longer closure duration for /tˤ/ to the tense articulation of the pharyngeal constriction which causes the contact for the closure to last for a long time. Al-

Nuzaili (1993) found that the emphatics were associated with longer closure duration than the plain consonants; the closure duration was 42% longer for the emphatics than it was for the plain ones in the unstressed context and 16% longer in the stressed one (see Table 2.12).

Table 2.12. Mean CD for the YA /t/ and /ṭ/ in milliseconds (Al-Nuzaili 1993)

		Speaker AA	Speaker WS
unstressed context	/ṭ/	96	78
	/t/	78	65
stressed context	/ṭ/	93	92
	/t/	86	75

At this point it is interesting to note that while VOT is generally longer for the emphatic than for the plain voiceless stops (see section 2.5.2), closure duration results show a different tendency whereby CD is longer for the emphatic than for the plain consonants. Such an inverse relation between these two acoustic parameters is explained by Weismer (1980) when combining closure duration and VOT for stops in different languages; closure duration thus decreases as VOT increases.

This claim is supported by evidence from the literature concerning VOT and closure duration of bilabial, alveolar and velar stops. Generally speaking, the further back the closure for a stop the higher the VOT as reported for Egyptian Arabic (Rifaat 2003) and for English (Klatt 1975; Cho and Ladefoged 1999; Bénki 2001). On the other hand, stop closure duration is observed to be longer in bilabials than in alveolars and velars in Italian (Esposito 2002). Thus higher VOT is associated with shorter CD and vice versa, suggesting the temporal compensation between CD and VOT. The cross-linguistic comparison surveyed by Hutters (1985) shows also a temporal relationship between closure duration and aspiration. The stops which have longer closure duration are associated with short aspiration as in Swedish and English while the languages which display shorter closure duration have long aspiration as in Danish and Hindi.

Some studies report no significant duration difference between the vowel in the emphatic context and the vowel in the plain context in Egyptian Arabic (El-Dalee 1984; Norlin 1987), Jordanian Arabic (Al-Masri and Jongman 2004) and in different Arabic dialects (Al-Bannai 2000). Similar results are observed for Gulf Arabic with the exception of the context of /ṭ/ and /t/ in which the vowel following /ṭ/ displayed significantly longer duration than that following /t/ (Hussain 1985). Hussain ascribed this to the absence of aspiration in /ṭ/ as compared to /t/, indicating that aspiration was manifested as a period of voicelessness occupying part of the following vowel. This seems to suggest that aspiration is considered by some researchers as being part of the vowel duration. For the effect of emphasis on vowel duration in Qatari Arabic, Bukshaisha (1985) notes that the vowels preceding the emphatic consonants are significantly longer than those preceding the plain consonants.

In Iraqi Arabic (IA), Hassan (1981) found a significantly longer duration for the vowel preceding the /sˤ/ context than that preceding the /s/ context, but no statistical significance between the duration of the final fricative /s/ and /sˤ/ in the context of the short /a/ and long /aː/ (see Table 2.13).

Table 2.13. Duration for final /s/ and /sˤ/ and the preceding vowel in IA (Hassan 1981)

word	V	duration	C	duration
/ba:sˤ/	/a:/	150	/sˤ/	95
/ba:s/	/a:/	125	/s/	95
/basˤ/	/a/	95	/sˤ/	135
/bas/	/a/	85	/s/	130

In a CV syllable, the total consonant-vowel duration may be similar for both emphatic and plain consonants. This is evident in the longer VOT for the plain voiceless stop than that for its emphatic counterpart while closure and vowel duration are longer in the emphatic than in the plain context. Such assumptions could be derived from the force of articulation theory (Belasco 1953) and the energy expenditure theory (Lindblom 1968) as these theories argue that the CV syllable duration is relatively similar, so there is an inverse correlation between the total duration of the consonant and the following vowel. The first theory suggests the effect of the consonantal articulation on the vocalic duration and the second theory assumes that the energy exerted in the production of the syllable is fixed. Both theories imply the existence of temporary compensation, which according to Machac and Skarnitzl (2007) shows that a longer duration of the consonant leads to a shorter duration of the adjacent vowel in a CV or VC syllable.

2.5.4. Summary of acoustic features

The first three formant frequencies, particularly F1 and F2, have been extensively employed by researchers to explore the acoustic manifestations of the emphatics so that they can be distinguished from their plain counterparts. The results of these acoustic investigations are normally used to reflect on what actually happens in the vocal tract during the production of the emphatics in terms of the secondary articulation. Findings from the literature show that the major role in the plain-emphatic distinction is played by F2 as compared to F1 and F3. The role of F3 is questioned by most researchers due to lack of consistency in F3 patterns as far as the plain-emphatic distinction is concerned, although F3 increase in the emphatic context is reported by some researchers. The effect of emphasis on formant frequency patterns depends on both vowel quality and vowel duration. Furthermore, speaker variability is reported in the production of both plain and emphatic consonants.

The general VOT pattern shows that the effect of the emphatic /ṭ/ on VOT decrease is evident in most but not all Arabic dialects (e. g., Iraqi, Jordanian, Libyan and Yemeni). In Egyptian Arabic, the VOT difference between /ṭ/ and /t/ is slight while in Sudanese Arabic, /ṭ/ has a longer VOT value than /t/. This cross-dialectal variability may be caused by different degrees of glottal opening as a function of the pharyngeal constriction in the production of the emphatic consonants; the longer the VOT value is, the greater the glottal opening is. This is because the pharyngeal constriction in the posterior part of the vocal tract affects the degree of glottal opening.

The emphatic segments are treated as having long articulations due to their greater intensity compared to their plain counterparts. However, most studies on Arabic dialects show that the emphatic consonant and the adjacent vowel are not significantly longer than their plain counterparts. Some other studies show a tendency for the emphatic context to be associated with longer duration than the plain context. This cross-dialectal inconsistency may suggest that the duration of segments in the emphatic environment may occur as a function of other controlling factors related to temporary compensation between acoustic parameters and the total duration of the syllable in addition to the effect of emphasis. As reported in the previous section, for instance, emphasis decreases VOT for the voiceless emphatic stops and this is accompanied by longer closure and vowel duration while in the case of the plain voiceless stops, the long VOT is associated with short closure and vowel duration.

2.6. Perception patterns

The available literature indicates that the perception of the emphatic consonant is conditioned by the presence of an emphatic vowel as confirmed by a number of studies (e.g., Obrecht 1968; Ali and Daniloff 1972a, 1974; Rajouni et al 1987; Al-Nuzaili 1993; Harrell et al 2003). For instance, an emphatic consonant that is separated from the following adjacent vowel is perceived as a plain consonant (Rajouni et al 1987). Therefore, the special way with which vowels adjacent to the emphatic consonants are pronounced in Moroccan Arabic led Harrell et al (2003) to refer to them as emphatic vowels.

Furthermore, Ali and Daniloff (1974) investigated the Iraqi listeners' ability of identifying the presence or absence of the emphatics /ṃ ð̣ ṣ ṭ ḳ/ in utterances where the emphatic and plain consonants were removed. The majority of listeners were still capable of perceiving emphasis on the adjacent vowels. This showed the role of the emphatic-induced coarticulatory effect in the perception of emphasis. The contextual effect of emphasis was therefore found to be a distinctive feature extending to adjacent vowels.

The perception of emphasis was also found to depend on F2 variation (Obrecht 1968; Al-Nuzaili 1993; Yeou 2001). Al-Nuzaili (1993) explored the role of F2 in the perception of the emphatics in Yemeni spoken Arabic, using synthetic stimuli in which the other acoustic parameters were fixed. F2 onset was varied for the /ṭi:/-/ti:/ continuum and F2 steady state for the /ṭa:/-/ta:/ continuum. A forced choice test showed that F2 onset variation was effective to enable listeners to identify /ṭi:/ as being different from /ti:/ and the mean crossover point was 1480 Hz. F2 steady state was also shown to be a sufficient cue in the emphatic perception in the case of the /ṭa:/-/ta:/ continuum; the mean crossover point was 1993 Hz. In a similar study carried out with Lebanese and Egyptian subjects, Obrecht (1968) determined the crossover point for the /ṭi:/-/ti:/ continuum to be 1450 Hz and the region of emphasis ranged between 1000 to 1400 Hz. It is clear that both studies displayed similar mean crossover points for the /ṭi:/-/ti:/ continuum.

The perceptual significance of F1 and F2 at the onset of /i:/ was also investigated by Yeou (1995, 2001) who used synthetic stimuli and varied the onset of F1 and F2 systematically for the /ṣi:/-/si:/ continuum. F1 onset variation was not reliable in perceptually distinguishing the /ṣ/-/s/ contrast, while the role of F2 in perceptually separating the pharyngealised consonants from the non-pharyngealised ones was crucially clear-cut. Having evaluated the category boundaries through the interpolation of the stimulus number at the 50% crossover, Yeou found that the boundaries for F2 were 1276 Hz and 1773 Hz for the pharyngealised and its non-pharyngealised counterpart respectively. The crucial difference between the two boundaries showed that an additional F2 onset lowering of 497 Hz was required for subjects to be able to recognise /ṣi:/, even if F1 onset did not have the expected value for /ṣi:/ (Yeou 1995, 2001).

The perception of the series /ṣ/-/s/ was also investigated by Zahid (1996) using Moroccan Arabic subjects and French-speaking speakers with no experience of Arabic. The /ṣ/-/s/ continuum was constructed by the systematic variation of F2 onset while other acoustic parameters were fixed. A forced-choice identification test showed that the Arabic group were able to label the two consonants with a clear category boundary at 1450 Hz whereas for the French group, the boundary was 1650 Hz. This resulted in the French subjects counting more stimuli as /s/. It was clear that the absence of the pharyngealised consonant in French might have caused the French subjects to encounter some difficulty perceiving the emphatic consonant, leading to confusing it with its plain counterpart.

Another investigation focused on Arabic and French subjects' ability to discriminate vowels in the emphatic context from those in the non-emphatic context (Znagui and Yeou 1996). Both Arabic and French subjects were able to distinguish two allophonic variants for the vowels /i: u: a:/ in the alveolar plain/emphatic comparisons whereas they were not capable of doing so in the alveolar/uvular and alveolar/pharyngeal comparisons. Znagui and Yeou attributed the subjects' ability to discriminate the alveolar/emphatic comparison to acoustic factors related to the role of the distance between F1 and F2 in the perception of vowels. The F1-F2 distance was close in the emphatic context if compared to that in the plain context. The importance of F1-F2 distance in the realisation of emphasis was also emphasised by El-Dalee (1984), Paddock (1970) and Amerman and Daniloff (1977). Furthermore, Znagui and Yeou (1996) ascribed the ability of French listeners to distinguish vowels in the emphatic context from those in the plain context to the French rich vocalic system.

The role of F1 in the perception of emphasis is not as efficient as that of F2. El-Halees (1985) assumes that F1 can be employed as a cue in order to differentiate the emphatic from the non-emphatic consonants, yet he admits that the major role in the perception of emphasis is played by F2. Although varying F1 onset was not effective enough to perceptually and contrastively distinguish between /ṣ/ and /s/, there was a trading relation between F1 and F2 (Yeou 2001). Both acoustic parameters contributed to the perception of the emphatic as shown by displacing the perceptual boundary by 497 Hz when F1 was activated.

The importance of F1 lies in its perceptual role in the distinction between uvulars and pharyngeals (El-Halees 1985; Alwan 1989). As F1 increases, listeners' perception changes from uvulars to pharyngeals, so F1 could act as a sufficient cue capable of distinguishing pharyngeals from the uvulars. It should be noted that vocal tract modelling studies showed the association between F1 increase and the pharyngeal constriction (see section 2.5.1.1) given that the lower the pharyngeal constriction is, the higher the F1 is. The exact location of the secondary articulation of the emphatics may also be important in determining the role of F1 in the perception of the emphatics. So for those dialects in which the pharyngeal constriction is located in the lower part of the pharynx, the F1 role may be reliable in the perception of emphasis.

The literature surveyed seems to focus on the role of the adjacent vowels in the perception of the emphatic consonants. Other consonantal cues may be relevant to the perception of emphasis (e.g., VOT and the intensity of the burst).

As discussed in section 2.5.2, VOT is found to be relevant to the plain-emphatic distinction. The intensity of the stop burst may also lead to a distinction between plain and emphatic consonants especially /t/and /tˁ/. This is due to the different degrees of aspiration between /t/and /tˁ/, and aspirated stops are associated with higher intensity bursts than unaspirated stops (Halle et al 1957). The spectral shape of the burst can also distinguish place of articulation for stops (Smits et al 1996) and therefore may provide cues for the plain-emphatic distinction. The burst for the voiceless stops is found to be more important in cueing place of articulation than that of the voiced stops.

2.6.1. Summary of perception patterns

Perceptual experiments used to test listeners' ability to distinguish the plain from the emphatic consonant take different forms, but provide consistent results that support the role of the vowel in the perception of emphasis. As indicted by Royal (1985), listeners perceive the emphatic consonants through their capability to colour adjacent segments with emphasis. Therefore emphatic coarticulation is relevant to the perception of emphasis. In fact, the perception of coarticulatory effects is reported in many studies (e.g., Alfonso and Baer 1982; Lisker 1986; Hawkins and Slater 1994; Hawkins and Nguyen 2004; Fowler 2005).

Acoustic parameters related to formant frequency patterns are also perceptually tested in order to assess their role in the plain-emphatic distinction. Not all the formant frequencies are equally reliable in doing so; F2 is found to hold most of the perceptual clues. The transition of the second formant frequency is expected to be the salient cue in speech perception (Delattre et al. 1955;

Liberman et al. 1967) given that it is the best acoustic parameter that encodes CV coarticulatory information. The F1 role is more obvious in distinguishing the uvulars from the pharyngeals than in the plain-emphatic distinction.

The coarticulatory patterns found in perception work on emphasis can be looked at in more detail in production work by examining the effect of emphasis on adjacent segments (see sections 2.5.1.2 on the effect of emphasis on formant frequencies, 2.7 on locus equations and 2.8 on emphasis spread).

2.7. Locus equation

Locus equations (henceforth LE) are found to be helpful in categorising place of articulation, taking into account that the degree of CV coarticulation varies depending on the consonantal place of articulation. This section focuses on the LE role in encoding CV coarticulation for the plain and emphatic consonants, starting with an introduction to the concept of coarticulation.

2.7.1. The concept of coarticulation

The term coarticulation was originally introduced by Menzerath and de Lacerda (1933) as a basic principle that governs speech and as an organiser of articulatory control (Kühnert and Nolan 1999). The term coarticulation is comprehensively employed to signal the systematic and mutual influences among close and distant segments (Farnetani and Recasens 1999). These influences are mainly due to an overlap of neighbouring articulatory gestures (Ladefoged 2001), which causes the adjacent segments to be similar (Kühnert and Nolan 1999). This similarity could be attributed to constraints imposed on the articulators. However, as will be discussed later in this section, coarticulation is by no means uniform and its patterns are anything but universal, which suggests that learned behaviour and speaker control play an important role too.

Coarticulation is classified into two types, namely anticipatory and perseveratory (Laver 1994). In anticipatory coarticulation, the production of a sound is affected by the following segment(s). In the case of the perseveratory or (carryover) coarticulation, the preceding segment influences the production of the following segment(s). On the basis of the direction of the coarticulatory effects, anticipatory coarticulation is also referred to as right-to-left and forward coarticulation while perseveratory coarticulation is called left-to-right and backward (Lubker 1981).

In order to account for VCV coarticulation, Öhman (1966) maintains that a VCV utterance is not a consecutive sequence of three gestures; instead the vowels are produced as one diphthong with the medial consonantal gesture being superimposed on the vocalic articulation that is present during all of the consonantal gesture. Öhman (1967) proposed the "superimposition" model of coarticulation to explain vowel-to-vowel coarticulation. According to Öhman, coarticulation can occur between two vowels through the intervocalic consonant. Similarly, the coproduction theory introduced by Fowler (1980) emphasises that the articulation of vowels and consonants being achieved through different articulatory movements paves the way for the temporal overlap between different gestures.

Since the concept of coarticulation as an overlap of sequential segments does not account for the segments that resist and block coarticulation, Bladon and Al-Bamerni (1976) coined the term "coarticulation resistance" as an articulatory control principle concerning the ability of a segment to resist inherently coarticulatory influences from adjacent segments. Thus a certain segment could reduce the degree of coarticulation with adjacent segments by restricting the magnitude of influence exerted by adjacent segments.

The development of the "degree of articulatory constraint" (DAC) model by Recasens et al (1997) was also an important step towards providing explanation for bidirectional coarticulatory influences of vowels and consonants. The predictions of this model suggested that in VCV sequences, increasing the level of constraint for the consonant would lead to strengthening the C-to-V effects and decreasing the V-to-C and V-to-V effects (Recasens et al 1997). The development of the DAC model by Recasens et al (1997) followed a comprehensive investigation of coarticulatory resistance in Spanish and Catalan by Recasens (1984, 1985, 1987, 1991) who indicated that the degree of coarticulatory resistance could vary with the consonant's demand on the articulators concerned. Accordingly, palatalised segments with alveolar articulation and velarised [l$^{\gamma}$] have a lesser degree of coarticulation than bilabial, dental and alveolar consonants due to a larger degree of constraint imposed on the tongue body in their production.

Electropalatographic and acoustic analysis of F2 showed that the Catalan dark /l$^{\gamma}$/ exerts more effect on the adjacent vowel than the Spanish and German clear /l/, however the velarised lateral in Catalan restricted V-to-V coarticulation compared to Spanish and German clear lateral (Recasens 1987, 1999; Recasens et al 1995; Recasens et al 1996; Recasens et al 1998). This effect is more obvious for the vocalic context of /i/ than /a/. The fact that /i/ received greater influence than /a/ accounts for the incompatible articulation between the velarised lateral and /i/. On the other hand, similarity between the articulatory configuration of back vowels and the velarised lateral causes the C-to-V coarticulatory influence to be slight (Recasens 1991). The phonetic similarity between a consonant and a vowel is reported between [i] and palatal consonants as well as between [w] and [u] (Recasens 1985). Moreover, acoustic analysis showed that formant frequencies at the CV boundary vary depending on coarticulation with the following vowel (Fant 1973). This is because the segments which are highly resistant to coarticulation produce the strongest coarticulatory influence on the adjacent segments and vice versa (Bladon and Nolan 1977; Farnetani and Recasens 1993).

In fact the sensitivity of coarticulatory effects to the context was also discussed within the window model of coarticulation proposed by Keating (1990) and the latest version of coproduction model by Fowler and Saltzman (1993). The effect exerted by a gesture on the vocal tract was said to be invariable; however, this gesture would encounter different degrees of coarticulation resistance which would vary depending on the demands imposed on the vocal tract configuration by the continuous gesture (Fowler and Saltzman 1993).

Coarticulation resistance may not show a consistent pattern across different languages and dialects. Bladon and Al-Bamerni (1976) accounted for cross-linguistic and cross-dialectal variation by indicating that coarticulation resistance should not be treated as a universal principle. Coarticulation is affected by phonetic and phonological constraints; these constraints are language-specific and associated with the inventory of the consonants and vowels of the language (Lindblom 1990; Manuel 1990; Beddor et al 2002; Gick et al 2006). Thus coarticulation is not only restricted to the effect of segments on one another as it has mental representation and constitutes part of the grammar of each language (Daniloff and Hammarberg 1973; Hammarberg 1976; Port et al 1980; Keating 1984). This means that each language and/or a dialect are characterised by its special patterns of organising coarticulation. Although different allophones are assumed to be resulting from physiological constraints of the speech production mechanism, this does not show a universal pattern across languages, indicating that coarticulation is learnt during language acquisition and stored in the brain. For instance, in the plain-emphatic distinction, Embarki et al (2007) found different coarticulatory patterns between different Arabic dialects and more interestingly coarticulatory patterns differ when speakers switch from their Arabic dialects to MSA (see section 2.7.4). This shows that speakers of a certain dialect learn not only the coarticulatory patterns of their own dialect, but also the pattern that is related to MSA.

This section has introduced the concept of coarticulation and focused on some coarticulation models that account for coarticulation resistance. This is because the emphatic consonants with which this study is concerned are thought to resist coarticulation with adjacent segments. The following sections shed some light on locus equation as an index of coarticulation and its role in separating the plain consonants from their emphatic counterparts.

2.7.2. Locus equation as an index of coarticulation

This section sheds some light on locus equations as an index of coarticulation through the regression analysis of F2 onset and F2 midpoint. The important role of F2 transition in the categorisation of the consonant place in a

CV syllable where F2 transition was dependent on the following vowel has long been investigated by Delattre et al (1955), who studied CV coarticulation using F2 locus. Later, locus equation parameters were derived by Lindblom (1963a) from the formula 2.1:

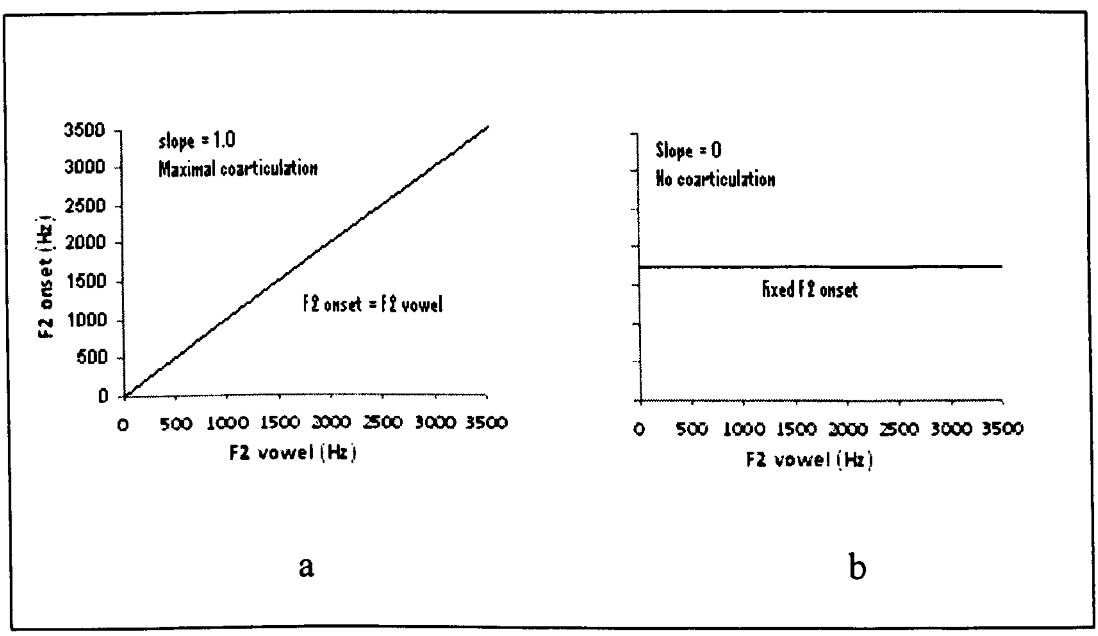
(2.1) F2 onset = k x F2 midpoint + c.

"k" stands for slope and "c" for y-intercept. Lindblom used one Swedish speaker producing word-initial /b d g/ in the CVC structure followed by 8 medial vowels. F2 onset was plotted along the y-axis and F2 midpoint along the x-axis. Regression lines for different consonants fitted to these plots revealed a linear relationship between F2 onset and F2 midpoint. Lindblom found that the slope value depended on the consonantal place of articulation, with the labial /b/ having a slope of 0.69, a slope of 0.28 for /d/ and a slope of 0.95 for /g/; y-intercepts were 410, 1225 and 360 Hz for the three consonants respectively (Lindblom 1963a). The slope results showed the different degrees of coarticulation between the consonant and the following vowel, the higher the slope value, the greater the CV coarticulation and vice versa.

Locus equation parameters resulting from the regression analysis also yield an R^2 value that ranges from 0 to 1. R^2 is a statistical measure that shows the degree of fitness of the regression line to the data points (Korey and Emenhiser 1998). As its value approaches or reaches 1, there is a good fit and when it is close to or 0, the fit is poor. The R^2 value accordingly could reflect any inter- and intra-speaker variability that exists since in the case of a high R^2 value, the plotted data is better clustered around the regression line and thus there is less variability.

The LE slope is often utilised as an acoustic measure of CV coarticulation (Krull 1987, 1988, 1989): If k = 0, then there is no coarticulation at all. However, if k = 1, then there is maximal coarticulation and the vowel onset value is the same as the vowel target. Figure (2.2a) represents an assumed example of maximal coarticulation in which F2 onset = F2 midpoint as manifested in the steepness of the regression line of the slope. This confirms the role of F2 onset-F2 midpoint difference in marking the degree of coarticulation. The smaller the difference is the better the CV coarticulation will be. On the other hand, Figure (2.2b) presents a state of no CV coarticulation; therefore, the slope value is zero and the slope of the regression line is parallel to the x axis. Locus equations encode transitional information for different consonants, inferring movement of the tongue body during the production of a CV sequence. The movement pattern of the formants is interpreted as the relation between two points, namely formant frequencies at the CV boundary and formant frequencies at vowel midpoint (Krull 1988).

Fig 2.2. Two cases of the degree of coarticulation (Krull 1988)



2.7.3. Studies of LE as a descriptor of place of articulation

This section looks at studies that have provided evidence for the role of LE parameters in categorising the consonantal place of articulation. There is also a focus on the factors that may lead to variation in the degree of coarticulation like manner of articulation, voicing, language and dialect.

Among those who examined the linear regression relationship between F2 onset and F2 steady state were Nearey and Shammass (1987) although the authors did not mention explicitly the concept of LE. They used CVd syllables where C was one of the voiced stops /b d g/ in the context of 11 medial vowels in Canadian English. Their results showed that the slopes were distinct across stops of different places with /g/ having the steepest slope (0.99) followed by /b/ (0.83), and the flattest slope is reported for /d/ (0.50).

A similar LE investigation was carried out by Sussman et al (1991) for American English, using the CVC syllable type with word-initial /b d g/ followed by ten vowels. The stop /b/ had the highest slope (0.89), the alveolar /d/ had the lowest slope (0.42) and the velar /g/ was associated with a relatively intermediate slope value (0.71). The slope differences were considerable across the three consonants. Sussman et al (1992) also extended the application of LE to data from children, using the word-initial /b d g/ in the CVC syllable structure. The slope for labial and velar consonants displayed some overlap, but the slope difference was significant between the labial and alveolar on the one hand and between the alveolar and the velar on the other hand. In Nearey and Shammass (1987) and Sussman et al's (1991, 1992) studies, the slope values showed how different voiced consonants yielded different coarticulatory patterns; the bilabial /b/ and the velar /g/ had more CV coarticulation than the alveolar /d/.

The study of locus equations was also applied to consonants with different places and manners of articulation. Sussman's (1994) results showed that the LE slope could distinguish three different groups despite differences in their manner of articulation: a bilabial group /b p m/, an alveolar group /t d n z/ and a velar group /k g/.

The generality of locus equation as a phonetic indicator of consonantal place has been debated when consonants vary in their manner of articulation. For instance, Fowler (1994) reported that /z/ and /d/ had statistically different LE slopes of 0.42 and 0.47 respectively although they had the same place of articulation. On the other hand, Sussman and Shore (1996) argued that the slope means for /d z n/ were similar as they were (0.40, 0.38 and 0.48) respectively.

It is clear that the slope values for both studies are similar. The slope difference between consonants of different manners of articulation is wider in Sussman and Shore's (1996) study than in Fowler's (1994) study. However, Fowler, unlike Sussman and Shore, indicates that the slope values as not being capable of distinguishing the place of articulation when consonants vary in their manner of articulation.

The measuring point seems to affect the slope value. Sussman and Shore (1996) indicated that /t/ had a similar slope (0.23) to /d/ (0.26) in a situation where F2 onset was measured at the first visible resonance during the aspiration interval for /t/ and at burst for /d/. Furthermore, while the /s/

slope (0.57) was significantly different from the slopes for the consonants /t d z n/, Sussman and Shore claimed that this might not have occurred if F2 measurements had been taken at the fricative interval. This seems to suggest that the fricative noise affects F2 transition from the consonant to the following vowel. The formant frequency measurement reported by Tabain (2000) showed that EPG data correlated very poorly with LE data when the consonant was a fricative. In fact, coarticulation is also quantified by means of regression analysis in articulatory studies of lingual consonants and vowels, using EPG analysis (e. g. Farnetani 1991; Farnetani and Recasens 1993; among others).

Yeou (1997) further reported that the slopes for the alveolar group /s/ (0.56) and /d/ (0.48) were significantly different from /t/ which had the steepest slope (0.66). This led him to conclude that LE might not be an indicator of place distinction when consonants have different manners of articulation, suggesting that the high slope for /t/ could be triggered by measurement limitations, not a phonetic interpretation. This was confirmed by Sussman and Shore (1996) as they measured F2 onset at the first visible resonance occurring during aspiration following the release. In Sussman and Shore's (1996) study, /t/ had a mean slope of (0.23) which was quite lower than that reported for /t/ at (0.66) by Yeou (1997) who measured F2 at vowel onset.

Another LE study, which investigated the LE parameters for both voiced and voiceless aspirated stops is by Modarresi et al (2005), who used five male speakers of American English and two male speakers of Persian. All speakers were treated as a single group as no statistical slope difference was found between English and Persian. Voiceless labial and coronal stops exhibited lower slopes than those for their voiced counterparts; however, this voicing difference for the slope was not reported for the velar stops (see Table 2.14).

Table 2.14. The LE slope for stops (Modarresi et al 2005)[3]

consonant	/p/	/pʰ/	/d/	/tʰ/	/g/	/kʰ/
Mean slope (1)	0.82	0.65	0.43	0.24	0.93	0.94
Mean slope (2)	0.72	0.65	0.29	0.24	0.95	0.94

The relevance of the measuring point to the LE slope was also investigated by Modarresi et al (2005); the slope difference changed with the measuring point. For instance, the slope was 0.43 for the voiced /d/ and 0.24 for the voiceless [tʰ] when F2 was measured at the first pitch period of the vowel following the stop release for the voiced /d/ and F2 onset for the voiceless /t/ at the earliest visible F2 resonance after the burst. However, when F2 was measured at the stop burst for the voiced stop, the slope was 0.29 for /d/ and 0.24 for [tʰ]. Thus, different measuring points could produce various F2 onset values that affect the LE slope when related to F2 midpoint.

Aspiration is therefore another variable that affects LE in addition to place of articulation. Engstrand and Lindblom (1997) investigated LE for the Swedish consonants /b d g p t k/ in five vocalic contexts. They adopted two

[3] Mean slope (1) obtained when F2 was measured at the start of the following vowel after the release burst for the voiced stops and at the earliest F2 resonance after stop release for the voiceless stops. Mean slope (2) obtained when F2 was measured very close to the stop release for the voiced stops.

measuring procedures; the first one was based on F2 locus and F2 target and the second one on F2 onset and F2 target. In the first procedure, they stated that long aspiration was associated with flatter slopes and a lesser degree of consonant-vowel coarticulation; the shorter the voicing lag was, the steeper LE slope was and vice versa. However, in the second procedure, long voicing lags caused the LE slope to be steeper. Thus, VOT interfered with place of articulation when LE was investigated as a determinant of place of articulation. In fact, it is reported that the coarticulatory effect is more obvious for the voiced stops than for the voiceless stops which have longer voicing lag than the voiced ones (Gay 1979; Engstrand 1989; Farnetani 1990; Modarresi et al 2004).

2.7.4. The role of LE in the plain-emphatic distinction

Researchers have recently investigated the LE role in distinguishing between the plain and emphatic consonants (e.g., Sussman et al 1993; Yeou 1997; Embarki 2006; Embarki et al 2007). This investigation is inspired by the nature of the emphatic consonants which are partly differentiated by the secondary articulation compared to their plain counterparts. This causes the emphatic consonants to affect the formant frequencies of the following vowel. Thus LE parameters, which use F2 to encode coarticulatory information, can show how the presence of the secondary articulation of the emphatic consonants affects the degree of CV coarticulation.

Sussman et al (1993) examined LE for /d/ and /dˤ/ in eight vowel contexts using three speakers of Cairene Arabic. Their results showed that the difference between /d/ and /dˤ/ was statistically insignificant for the slope and significant for the y-intercept (see Table 2.15). The lower slope for /dˤ/

than for /d/ was suggestive of a flatter slope for /dˤ/. Therefore, the emphatic consonant resists coarticulation with the following vowel more than the plain consonant.

It was also noted that inconsistent LE slope results were reported; results from the second speaker showed the highest slope value for /dˤ/ across all the plain and emphatic tokens of all speakers (see the shaded box in Table 2.15). This signalled the presence of inter-speaker variation as far as the LE slope was concerned although this investigation involved a small number of subjects. Still, y-intercept values for the three speakers were consistent and suggested that the low y-intercept for /dˤ/ reflects the decreasing effect of the secondary articulation of the emphatic consonant on F2 onset (Sussman et al 1993).

Table 2.15. LE parameters for /d/ and /dˤ/ (Sussman et al 1993)

speaker	/d/			/dˤ/		
	k	c	R^2	k	c	R^2
1	0.267	1278	0.83	0.153	954	0.43
2	0.228	1286	0.59	0.319	839	0.88
3	0.240	1356	0.60	0.155	1005	0.47
mean	0.25	1307	0.67	0.21	933	0.59

The role of LE in the plain-emphatic distinction was examined for MSA produced by Moroccan speakers (Yeou 1997). Yeou's material included both real words and nonsense words of the sequence CVCVC (VC) in which plain and emphatic consonants occurred word-initially and were followed by one of the vowels /ɪ æ ʊ iː æː uː/. The emphatic context had a remarkably lower slope than the plain one (see Table 2.16), suggesting that the emphatic consonant showed more resistance to vowel articulation than the plain consonant.

Moreover, the mean values showed that y-intercept was relatively lower for the emphatic than for the plain context apart from the /t/-/tˤ/ contrast. These lower y-intercept results for the emphatic context were not consistent for all speakers (Yeou 1997). Only speaker 6 had lower y-intercept for the plain /ð/ than the emphatic /ðˤ/; speakers 4, 5 and 6 had lower y-intercept for /d/ than /dˤ/, speakers 5, 7 and 8 had lower y-intercept for /s/ than /sˤ/ and speaker 1-8 had the same y-intercept values for /t/ and /tˤ/.

Table 2.16. Mean LE parameters for MSA in Yeou's (1997) study

/ð/			/d/			/s/			/t/		
k	c	R^2	k	c	R^2	k	c	R^2	k	c	R^2
0.46	875	0.83	0.48	936	0.85	0.56	741	0.86	0.66	623	0.90
/ðˤ/			/dˤ/			/sˤ/			/tˤ/		
k	c	R^2	k	c	R^2	k	c	R^2	k	c	R^2
0.22	778	0.62	0.31	839	0.66	0.35	681	0.70	0.37	678	0.79

Embarki et al (2006) further investigated the role of LE in the plain-emphatic distinction in MSA produced by 8 speakers from eight different Arab countries. They used word-initial plain and emphatic consonants followed by the vowels /i u a/. Their results confirmed the lower slope for the emphatic consonants as compared to their non-emphatic counterparts (see Table 2.17).

Table 2.17. LE parameters for MSA in Embarki's (2006) study

	non-pharyngealised				pharyngealised			
C	/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
c	531	579	524	411	570	479	325	439
k	0.75	0.66	0.75	0.74	0.47	0.54	0.64	0.48
R^2	0.95	0.88	0.85	0.90	0.88	0.87	0.89	0.84

A more recent study by Embarki et al (2007) investigated LE parameters for the emphatics /tˤ dˤ sˤ ðˤ/ and their plain counterparts in MSA and four Arabic dialects (Yemeni, Kuwaiti, Jordanian and Moroccan). Sixteen speakers were recruited for the study; each dialect is represented by four speakers. The syllable structure VCV was used in which C was either a plain or an emphatic consonant. F2 was measured at the onset and midpoint of V2. Such a study allowed for a comparison of the slope between the plain and emphatic consonants in these four dialects and MSA in addition to a cross-dialectal comparison.

In MSA the slope value was lower (flatter) for the emphatic consonants /tˤ dˤ ðˤ sˤ/ than that for their non-emphatic counterparts (see Table 2.18). The effect of the emphatic /sˤ/ on slope lowering was less evident than that of other emphatics. For the Arabic dialects the emphatic consonants /dˤ sˤ ðˤ/ had lower slope values than their plain counterparts; the slope for /dˤ/ and /ðˤ/ was flatter than that for /sˤ/ (see Table 2.18). The slope for /tˤ/ (0.595) did not seem to considerably distinguish it from that for /t/ (0.592). This showed a difference between Arabic dialects and MSA. Generally speaking, the slope in the Arabic dialects was flatter than that for MSA. This, in turn, reduced the slope difference between the plain and emphatic consonants in the Arabic dialects as compared to MSA.

It was evident that speakers' switching from MSA to their native dialect affected LE slope values. Thus, acoustic cues characterising the same CV sequence differ depending on language variety; such a difference reflects variety-specific articulatory adjustments which are not transferable and which might result from different mental representations between MSA and Arabic dialects (Embarki et al 2007).

Table 2.18. Mean LE parameters for MSA and Arabic dialects (Embarki et al 2007)

Modern Standard Arabic (MSA)								
	non-pharyngealised				pharyngealised			
	/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
c	423	515	335	385	473	434	262	420
k	0.773	0.712	0.813	0.765	0.545	0.573	0.766	0.555
R^2	0.910	0.823	0.908	0.925	0.763	0.774	0.846	0.792
Arabic dialects								
	non-pharyngealised				pharyngealised			
	/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
c	754	719	396	559	445	587	450	452
k	0.592	0.618	0.796	0.667	0.595	0.479	0.662	0.516
R^2	0.777	0.782	0.891	0.864	0.829	0.653	0.684	0.722

Results for four Arabic dialects showed that the slope values for the emphatic consonants could classify two geographical areas, namely eastern and western. The slope value for the pharyngealised consonants /tˤ dˤ sˤ ðˤ/ in the eastern dialects was flatter than that of the western dialects represented by Moroccan Arabic (see Table 2.19). The slope was lower for the pharyngealised consonants than it was for the non-pharyngealised ones apart from Moroccan Arabic in which the slope was inversely lower for the plain consonants than it was for the emphatic ones. This suggested that the emphatic consonants in Moroccan Arabic had more CV coarticulation than the plain consonants and thus they exhibited less coarticulatory resistance to coarticulation with the following vowel as compared to their plain counterparts.

Table 2.19. Mean LE parameters for four Arabic dialects (Embarki et al 2007)

Arabic dialects		Non-pharyngealised				pharyngealised			
		/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
Jordanian Arabic	c	676	479	614	519	509	668	485	622
	k	0.628	0.773	0.662	0.661	0.526	0.389	0.589	0.406
	R^2	0.952	0.959	0.919	0.881	0.873	0.814	0.915	0.895
Kuwaiti Arabic	c	665	764	513	595	425	624	661	557
	k	0.657	0.614	0.726	0.650	0.600	0.431	0.513	0.506
	R^2	0.682	0.639	0.705	0.724	0.804	0.527	0.388	0.808
Moroccan Arabic	c	817	1010	185	660	370	542	75	407
	k	0.555	0.451	0.926	0.628	0.691	0.593	0.937	0.648
	R^2	0.776	0.763	0.975	0.890	0.867	0.763	0.896	0.891
Yemeni Arabic	c	874	758	322	473	566	647	797	524
	k	0.515	0.591	0.833	0.720	0.448	0.389	0.423	0.547
	R^2	0.816	0.866	0.945	0.931	0.823	0.634	0.239	0.409

2.7.5. Summary of locus equation

This section introduced the concept of coarticulation in order to define coarticulation and explain coarticulatory effects in light of the related models of coarticulation. The survey also included the role of LE in providing CV coarticulatory information which depends on the consonantal place of articulation and how this role is affected by some variables like voicing and the manner of articulation. The general patterns show that LE parameters are found to distinguish the plain from the emphatic consonants, with the latter class being associated with flatter slopes than the former and thus exerting greater coarticulatory resistance to vowel articulation, however the language variety and the dialect could lead to variation in the realisation of LE parameters.

2.8. Emphasis spread

Emphasis spread has been studied in different Arabic dialects. These studies aim to represent the effect of emphasis on both adjacent and distant segments, whether vowels or consonants. In section 2.5.1.2, this effect is examined only for formant locus at the consonant and formant frequencies of adjacent vowels.

Emphasis spread is referred to as a process of coarticulation effect (Mustafawi 2006) and as the spread of a phonological feature, i.e. pharyngealisation, to more than one segment through a regular pattern (Owens 1993). This is because coarticulation is indisputably a complex phonetic and phonological process (Boyce 1990; Coleman 2003). According to Youssef (2006), emphasis spreads from an underlying segment and expands over a large domain which is not restricted to one segment.

Different phonetic and phonological terms are employed to represent the spread of the emphatic gesture. For example, Hoberman (1989) uses the feature [+constricted pharynx] and El-Dalee (1984) and (Mustafawi 2006) use the feature [+retracted tongue root] to represent the articulation of emphasis while Card (1983) employs the feature [+F2 lowering] in capturing the crucial acoustic feature of emphasis. Heath (1987) adopts both the phonological term [+emphasis] and the phonetic term [+ pharyngealisation].

Generally speaking, it is possible for the back movement of the tongue root to influence the production of neighbouring vowels and consonants (Card 1983). Yet some segments are found to block the spread of the emphatic gesture, suggesting that these segments show resistance to the emphatic articulation. These blocking segments include /i/, /j/ and /ʃ/ (Ghazali 1977; Card 1983; Hussain 1985; Heath 1987; Younes 1993; Davis 1995; Shahin 1997). Heath (1987) adds /ʒ/ and Shahin (1997) /tʃ/ and /dʒ/ as blockers to emphasis spread. During the production of these sounds, the vocal tract adopts an articulatory configuration that involves the fronting of the tongue dorsum while in the production of the emphatics the tongue is retracted. These conflicting articulatory gestures act as blockers of emphasis spread.

The coarticulatory effect of emphasis on a high front vowel may either be weakened or completely prevented especially if the vowel is long (Ghazali 1977). For instance, neither the final /n/ in /ṭi:n/ (mud) nor the initial /b/ in /bi:ḍ/ (white) acquires emphasis in Tunisian Arabic due to emphasis spread being blocked by /i:/. Likewise, Card (1983) indicates that segments distinguished acoustically by a high second formant frequency behave similarly in blocking emphasis spread. These segments include /i: e: j ʃ/ which carry the feature specification [+high, -back]. Furthermore, Laradi's (1983) xeroradiograms of the vowel /i:/ in /ti:n/ and /ṭi:n/ show that there is considerable similarity between the vowels in both words.

Contrary to other researchers, Bukshaisha's (1985) electropalatographic study shows that palatal segments do not block the spread of the emphatic gesture as in the example word [ṇạʃị:ṭ] (active) in which emphasis spreads from the final /ṭ/ to all four preceding segments and thus the whole word is emphatic. A similar tendency is reported for the high front vowel /i:/ in [ṭị:ṇ] (mud) (Bukshaisha 1985). These results are surprising if one takes into account the previous results concerning the tendency of palatal articulations to resist the emphatic gesture. The question is what makes these articulations acquire the emphatic gesture if they are well-known to be antagonistic to emphatic articulations. This may reflect dialect-specific features since the domain of emphasis spread could vary, depending on the dialect. Watson (1999) provides further support for the role of the dialect in spreading emphasis as in Qatari Arabic emphasis spreads to the whole word and only to neighbouring vowels in Abha, a dialect spoken in Saudi Arabia

The emphatic consonants also affect other non-emphatic consonants particularly those which have a vowel-like formant structure such as nasals, liquids and voiced fricatives as evident in their low F2 (Bukshaisha 1985). In the word [ṇịṣị:ḅ] (luck) in which the emphatic /ṣ/ is surrounded by two front vowels, emphasis spreads to the whole word, so syllable boundary does not prevent emphasis spread in both directions (Bukshaisha 1985). Bukshaisha also provides an example from Qatari Arabic in which the emphatic /ṭ/ in the second word in [ḅẹ:ṭ#ṭạ:jịṛ] (flying house) spreads to cover both the rest of the second word and the whole first word. This gives evidence for the fact that neither word boundary nor /e:/ blocks emphasis spread.

The role of the distance from the emphatic consonant in spreading the backing gesture is discussed by Ghazali (1977). An examination of the words /biḍi:ʕ/ (to be lost) and /bifi:ḍ/ (to overflow) show that the prefix "bi" in [ḅịḍi:ʕ] displays more backing than the prefix "bi" in /bifi:ḍ/ due to the distance from the emphatic /ḍ/. This analysis confirms the gradient nature of the effect of emphasis which fades away as the segment distances from the underlying emphatic consonant.

On the other hand, the back vowels /u u: o:/ and the low vowels are found to acquire and allow emphasis to spread to other segments (Hussain 1985).

Card (1983) indicates that back articulations like /u:/ and /w/ have the feature, low F2 which they share with the emphatic context.

Examples of entirely emphatic words presented by Card (1983) show that the low vowel does not block the spread of the emphatic gesture which can also be transmitted through the pharyngeal consonant /ʕ/ to other segments, e.g., [ḅạ:ṣ] (bus) and [ḅạʕ̣ḍ] (some). The fact that the low vowel is backed in the emphatic context (Card 1983) paves the way for the spread of the emphatic gesture from the underlying emphatic /ṣ/ to the preceding segments in the first example, and from the emphatic /ḍ/ to other segments including [ʕ̣] in the second example. This pharyngeal alone may not trigger emphasis in the adjacent segments. This is because pharyngeals have limited coarticulatory effects on adjacent segments (Ghazali 1977). Furthermore, pharyngeals have sometimes been considered emphatic due to the auditory impression which is close to that of pharyngealised sounds (Al-Nasser 1993). The auditory impression of emphasis on a pharyngeal may also be enhanced in the presence of a pharyngealised consonant.

In Palestinian Arabic, emphasis does not spread beyond word boundary as in [ṭụ:ḅạḳ#kama:n] (a brick too) (Card 1983). Emphasis in the first word spreads from the emphatic /ṭ/ to cover the whole word, but it does not extend to the second word. Laradi's (1983) endoscopic results shows that in the word [ḍạ:ḷạ:ḷ] (backsliding) emphasis spreads from /ḍ/ to the whole word.

The scope of emphasis spread may vary from one variety to another. Lehn (1963) indicates that in Egyptian Arabic the minimum domain of emphasis is the sequence C+V, not V+C and the entire syllable is either emphatic or plain in a monosyllabic utterance as shown by the following examples: [ṛạḅ] (lord) and /rab/ (spouted). The fact that the minimum domain of emphasis is the syllable for Egyptian Arabic is also adopted by Mitchell (1993) and Harrell (1957). On the other hand, for Davis (1991), the domain of emphasis in Cairene Arabic is the word. Emphasis spread covers even the prefixes as a result of the presence of the emphatic /ḍ/ in the stem in Cairene Arabic as in the example: [ḅạf̣ạḍ:ạḷ] (I prefer). These prefixes are pronounced with no pharyngealisation when the root has no emphatic consonant as in /baktɪb/ (I write) (Davis 1991).

In Tripoli Libyan Arabic, Laradi (1983) views emphasis as a feature of the syllable as emphasis can be realised within the syllable structure CV or VC. The emphatic gesture could affect any vowel as long as it occurs within the syllable and this gesture could extend to other adjacent syllables only if they have the low vowels /a/ and /a:/. In Lebanese Arabic, Obrecht (1968) considers the domain of emphasis spread to be the sequence CV or VC and thus the whole syllable is emphatic if its syllable type is CVC. In Iraqi Arabic, the minimum domain of emphasis is CV, but an entire word is never emphatic even if it is a monosyllabic word (Ali and Daniloff 1972a, 1972b). In all dialects examined by Ghazali (1977), the maximal domain of emphasis is the word.

The majority of researchers consider emphasis to be a distinctive feature of the consonant (Mitchell 1956; Harrell 1957; Maamouri 1967; Ghazali 1977; Card 1983; Haddad 1984; Hussain 1985; Al-Bannai 2000; Younes 1993, 1994). This approach treats emphasis as an underlying characteristic of one segment in a word that spreads from that point to affect adjacent segments in various degrees. Haddad (1984) presents interesting discussion as an attempt to account for the assumption related to the treatment of emphasis as a property of one single segment. He considers the careful speech of some Lebanese speakers to provide some evidence for this assumption, a situation where part of the stem loses its emphasis due to resyllabification and the emphatic is realised as a plain consonant. For example, the word for (the stomachs) is pronounced in two different ways as [libṭu̞:n̞] or [l̞u̞b̞ṭu̞:n̞]. Haddad argues that considering emphasis to be a feature of the whole stem requires all segments in the stem to equally have the same degree of emphasis in addition to their capability of controlling the spread of emphasis from the emphatic /ṭ/.

Other researchers regard emphasis as a suprasegmental feature which takes the syllable as its structural domain (e.g., Ferguson 1956; Firth 1957; Lehn 1963). Lehn (1963) rejects the traditional segmental approach in favour of a prosodic approach, indicating that emphasis should be treated neither as a feature of the consonant nor the vowel, but as a redundant feature of both. Zangui and Yeou (1996) argue that the effect of emphasis on the vowels, which is realised acoustically and perceptually, should not determine the phonological identity of the vowels as this phonological identity is represented by the emphatic consonant. This lends credence to the proposal that the source of emphasis is initiated by the emphatic consonant whereas the vowel is involved in a coarticulatory process with the adjacent emphatic.

2.8.1. Summary of emphasis spread

Emphasis spread is a coarticulatory process by means of which a phonetic feature is superimposed on the articulation of adjacent segments. Most researchers view emphasis as a feature of the consonant that spreads to cover neighbouring segments. Other researchers regard emphasis as a suprasegmental feature and the domain of emphasis is the syllable, the word or possibly longer utterances. Emphasis spread also depends on the dialect as certain so-called blocking segments could allow its spread in some, but not all dialects. In fact emphasis poses problems in phonology as a result of the difficulties associated with identifying the spread of the emphatic gesture (Kaye and Rosenhouse 1997). These difficulties are due to the lack of a uniform pattern that characterises emphasis spread in all Arabic dialects.

2.9. Sex and gender differences

It has been reported in a number of studies that males generally tend to produce emphatics with a greater degree of emphasis than females (Harrell 1957; Lehn 1963; Khan 1975; Royal 1985; Mitchell 1990). Harrell (1957) provides an example of a woman who realised the emphatic /ḍ/ in the word /ḍala:l/ (backsliding) as a plain [d] so this word becomes [dala:l] and has therefore a different meaning (spoiling). Harrell also presents an example from certain styles of Cairene Arabic in which certain words have both emphatic and non-emphatic pronunciation; e. g., [ra:gil] for /ṛa:gil/ (man) and notes that the plain realisation can be treated as effeminate.

In his phonological study of emphasis, Lehn (1963) confirmed that in Cairene Arabic, women's production of emphasis was characterised in general by being less prominent if compared to that of men. Royal (1985), who carried out a sociolinguistic study of pharyngealisation in Egyptian Arabic, used the term "strength of pharyngealisation" to refer to gender differences in the degree of pharyngealisation. She indicated that strong pharyngealisation, which was a characteristic of men's speech, was viewed as unfeminine if detected in women's speech. Royal (1985) further found that women tended to palatalise /ṭ/ and /ḍ/ before [i] in Cairene Arabic more than men, describing this as a fronting tendency. This tendency was also observed in the speech of women in Cairene Arabic, especially those under the age of 50 (Haeri 1996).

The tendency to reduce the degree of emphasis was also observed in the speech of women and children in Tunisian Arabic (Maamouri 1967). Maamouri neither dismissed their ability to produce emphasis altogether nor referred to men as having stronger emphasis than women; however, he claimed that there are phonetic variation with respect to the degree of emphasis.

Khan (1975) carried out two acoustic investigations in order to compare the emphatic with the non-emphatic consonants as produced by males and females. In the first study, two males and two females from Egyptian Arabic were employed. Khan measured F1 and F2 of the following vowel at 80 ms after the consonantal release and found that the F2 difference between the emphatic and the non-emphatic contexts was smaller for women than it was for men. However, this effect was not obvious for F1. In the second study, Khan (1975) included six male and five female American learners of Arabic. In this case, there was a slight difference between the formant frequencies in the emphatic and the plain contexts for both males and females. This shows that foreign learners of Arabic intend to de-emphasise the emphatics due to the lack of the emphatics in their language. Furthermore, this may be because both males and females are exposed to the same linguistic input.

As Khan (1975) reports that American women and men do not differ in the way they produce the emphatics while the Arabic subjects differ, she uses these results to refute Fant's (1966) hypothesis that formant frequency differences are related to the sex of the speaker. This implies that although there are sex differences in the formant frequency patterns, some sociolinguistic factors can also interfere in characterising gender differences as far as the production of the emphatics is concerned.

Another acoustic study was carried out by Ahmed (1979) on emphasis in Cairene Arabic. Ahmed measured the mid point of the formant frequencies F1, F2, F3 and F4 of the vowels /i: u: a:/ in the emphatic context of /ḍ/ and the plain context of /d/ for both males and females. The main difference between male and female was that the F2 decrease was more considerable in the emphatic context of the males than in that of the females (1979). This confirms the results of the previous studies which indicated that men tend to emphasise more than women and showed particularly similar results to those reported by Khan (1975) for her Arabic speakers.

A study conducted by Khattab et al (2006) on Jordanian Arabic shows that the degree of emphasisation is affected by gender; in this case overlap between the plain and emphatic contexts was reported for females, but not males as reflected in the range for F1 and F2 at vowel onset. 33% of the post-emphatic vowels produced by the female subjects exhibited onset frequencies of the front quality that were associated with the plain context. This was supported by auditory analysis in which female speakers from Amman showed various degrees of emphasisation, but not the females from Irbid. Khattab et al (2006) wondered whether the sociolinguistic variability was triggered by gender, locality or both.

On the other hand, another study on gender differences in Jordanian Arabic (Al-Masri and Jongman 2004) yielded results that were contradictory to those reported by Khattab et al (2006) and other studies. Al-Masri and Jongman's (2004) results showed that for females the emphatic context, as compared to the plain one, decreases F2 of adjacent vowels by 704 Hz as opposed to 565 Hz for males and concluded that emphasis was more prominent for females than males.

Khattab et al (2006) attributed the different results between their study and Al-Masri and Jongman's (2004) study to reasons like locality, the tendency for women to reduce the degree of emphasis in their speech, particularly old generation and the different material employed in both studies. It should be pointed out that Al-Masri and Jongman (2004) mention neither the vocalic context nor the emphatic consonants involved. Moreover, they do not determine where F2 measurements were taken from, e.g., the onset, the steady state etc. This could also make it difficult to speculate about the possible potential reasons that led to the different results in the two studies.

Studies on gender differences show that sociolinguistic factors seem to affect the realisation of the emphatic consonants in Arabic. These differences are acoustically manifest in F2.

2.10. The acquisition of the emphatic consonants

The emphatic consonants have complex articulations since their production involves a secondary articulation in addition to the primary one, and they also have a number of other articulatory correlates (see section 2.4.2). Therefore it is of interest to explore how the acquisition of such class of sounds may be affected by this articulatory complexity. In fact, more work has been devoted to the investigation of the phonetic features of the emphatics as produced by adults than their acquisition by children and younger generations. Amayreh and Dyson (1998) indicate that little data has been found about the acquisition of Arabic and its phonology as the majority of studies concentrate on the speech sounds of the adults.

The acquisition of the emphatic sounds occurs at a later stage compared to that of other consonants in Arabic. The emphatic consonants are included among those consonants which are acquired at a late stage in Jordanian Arabic and Egyptian Arabic (Omar 1973; Amayreh and Dyson 1998). Omar (1973) indicates that the emphatics are realised as their plain counterparts in the speech of native speakers of Egyptian Arabic at the early stages of acquiring their first language. There is a complete mastery of the production of the emphatic consonants in Arabic by children at the age of six and half a year (Dylson and Amayreh 2000).

The acquisition of the emphatic consonants is described as being more difficult than other consonants (Amayreh 2003). This difficulty could be associated with their complex articulation which involves forming two articulations simultaneously. Support to this claim comes from Dylson and Amayreh (2000) who discuss the concept of de-emphasis where consonants lose their secondary articulation as a type of error committed by children and that declines with age.

Similar patterns are found in the speech of L2 learners of Arabic. An investigation of the L1 transfer of phonetic features to L2 has shown that American learners of Arabic tend to use the non-emphatic consonants instead of the emphatics (Huthaily 2003). Accordingly, /ṭ/ is realised as [t], /ṣ/ as [s], /ḍ/ as [d] and /ð̣/ as [ð] or rarely as [d]. Therefore, foreign learners of Arabic are not capable of producing the Arabic emphatics; a situation where the plain consonant is confused with the emphatic one causing, especially with respect to minimal pairs, a phonological problem where foreigners fail to convey the proper meaning of the word.

Therefore, both L1 Arabic children and L2 English learners of Arabic are faced with the difficulty of producing the emphatics due to the complexity of the secondary articulation of the emphatics and due to possibly L1 transfer in the case of the latter group. This complexity hinders their progress towards establishing the secondary articulation, however children can overcome this difficulty as they grow up and experience articulation.

This suggests that in the case of the emphatic consonants which have two articulations, one articulation is established first. In this case the primary one is mastered earlier than the secondary one possibly due to the importance of the primary articulation over the secondary one. Furthermore, the primary articulation could be easier to achieve than the secondary one. Evidence for this may be implied by the fact that the emphatic consonant is replaced by its plain counterpart at the early stages of language acquisition as discussed earlier in this section. In the case of the foreign learners of Arabic, the difficulty of emphatic articulation is a problem enhanced by some other factors associated with L2 learning difficulties.

Consonants associated with primary back articulations such as the pharyngeal /ʕ/ and the uvular /q/ follow the same acquisition pattern as the emphatic consonants and are acquired at a late age; however, the voiceless pharyngeal /ħ/ is acquired at an early age (Amayreh and Dyson 1998). As the two pharyngeals are acquired at different states, Amayreh and Dyson (1998) argue that the early acquisition of /ħ/ is attributable to the fact that young children are frequently exposed to words with this consonant. This discrepancy is explained by Ingram (1989) who indicates that the acquisition of the most frequently heard sounds occurs at an early age.

2.11. Concluding remarks

This chapter has discussed the notion of emphasis in Arabic. The emphatic consonants exist in the vast majority of Arabic dialects. Some emphatics are referred to as primary emphatics, e.g., /ṭ ḍ ṣ ð̣/; these have a phonemic function and are more frequent than other consonants which are regarded by some researchers as emphatics. The emphatic consonants are characterised by having a number of articulatory features in addition to the primary articulation which they share with their non-emphatic counterparts. These features include the main secondary articulation which can vary between velarisation, uvularisation and pharyngealisation, and other articulatory correlates like lip rounding, larynx raising and retraction of the primary articulation. These additional correlates occur as a function of tongue retraction to achieve the secondary articulation.

The secondary articulation of the emphatics affects a number of acoustic parameters such as the first three formant frequencies of adjacent vowels, particularly F1 and F2, VOT and locus equations. The slope of locus equation provides coarticulatory information. Generally speaking the magnitude of the effect of emphasis on these acoustic parameters could depend on the vocalic context, dialect, speaker and gender. The effect of emphasis on the duration of segments is not consistent across different Arabic dialects. Furthermore, as the coarticulatory effect of emphasis is manifest in the adjacent vowels, emphasis is perceived on the vowel. Emphasis can also spread to distant segments and adjacent words; this depends on the dialect. The fact that the emphatic consonants have a secondary articulation makes it difficult for children to acquire them; therefore, their acquisition occurs after the acquisition of their plain counterparts.

This chapter aims at defining emphasis, describing its phonetic features and providing the theoretical grounds that account for the results of the current study. As the phonetic features of emphasis could vary cross-dialectally, this allows for an opportunity to compare the acoustic features of the Libyan Arabic emphatics with those of other Arabic dialects. This would also offer an insight into determining the methods to be followed in taking the acoustic measurements. The next chapter describes the methodology adopted in collecting the data for this study and how the acoustic measurements are taken.

PART TWO

METHODOLOGY, RESULTS AND DISCUSSION

Chapter Three

Methodology

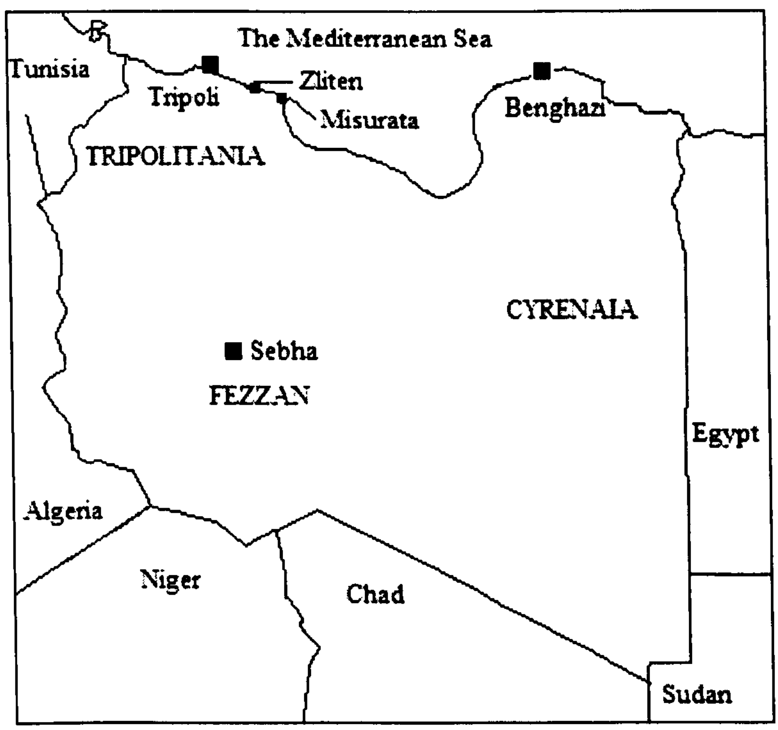
3.0. Introduction

This study investigates the role of a diverse range of acoustic parameters in characterising the emphatic consonants in Libyan Arabic. These acoustic parameters include the first three formant frequencies in the following vowel, locus equation and various duration indices. A comparison is carried out as far as these parameters are concerned. Formant frequencies at the onset and midpoint of the vowel following the plain and emphatic consonants are measured in order to trace the effect of emphasis on the following vowel. An auditory analysis of the vowel quality is also carried out to determine the vowel allophones in the plain and emphatic contexts. Locus equation parameters are elicited through a regression analysis of F2 onset and F2 midpoint. Furthermore, the effect of emphasis on the duration is examined for CD (Closure Duration), VOT (Voice Onset Time), VD (Vowel Duration) and FD (Fricative Duration) in addition to its effect on the intensity of the emphatic fricative. Different measurement procedures are adopted for these acoustic parameters and these will be discussed later in this chapter.

3.1. The dialect investigated

Libya is located in the heart of the Arab world and has a large area of about 1, 759,540 sq km with a population of 6,310,434 according to a 2008 survey[4]. Information about the population and the area of Libya and Zliten are taken from wikipedia as there are no other reliable sources of information on this at the moment. The official language spoken in Libya is Arabic, and English is used for trade purposes and as a foreign language in educational institutions. The dialect investigated in this study is the variety of Libyan Arabic spoken in the costal city of Zliten which is situated in the north of Libya between the cities of Khums and Misurata (see Figure 3.1).

Fig. 3.1. The location of the dialect investigated in this study[5]



Zliten is 150 kilometres to the east of Tripoli, the capital city of Libya and has a population of 184, 884 at the last census in 2006[6]. Zliten is located within the boundaries of the Tripolitanian region which is part of the western

[4] http://ar.wikipedia.org/wiki/Libya [Accessed 08.05.2009].
[5] http://geography.about.com/library/blank/blxlibya.htm [Accessed on 08.05.2009].
[6] http://ar.wikipedia.org/wiki/%D9%85%D9%86%D8%B7%D9%82%D8%A9_%D8%B2%D9%84%D9%8A%D8%AA%D9%86 [Accessed on 08.05.2009].

dialectal area in Libya (see chapter one, section 1.1). The Zliten dialect is similar to the Tripoli dialect because of geographical reasons as Zliten and Tripoli are western Libyan cities. The people who live in Zliten are also in contact with others who live within the Tripolitanian region for purposes related to trade, study and for other administrative purposes. Moreover, most people who live in Tripoli are originally from the surrounding Libyan cities, one of which is Zliten. According to the researcher's intuitive knowledge, the Zliten dialect exhibits similarity to Tripoli Libyan Arabic and the dialects spoken in the Tripolitania region at the level of the vocabulary used and phonetic and phonological aspects. The vowels and consonants used in Tripoli are similar to those found in the Zliten dialect. The majority of the Libyan population live in the Tripolitania region; therefore, the Zliten dialect represents a wide geographical area and a heavily populated area of Libya. For such reasons, the choice of this dialect is justified as being representative of the majority of Libyan population.

3.2. Informants

The total number of informants in this study was twenty native male speakers of Libyan Arabic. Their age ranged from 27 to 40 years old and the average age for speakers was 34 (see Table 3.1). The speakers were located through following the friend-of-a-friend technique by asking friends and acquaintances to participate in this study and seeking their help to find more required speakers. In order to provide an opportunity for better representation and generalisation of the results, this study employed a greater number of speakers compared to other studies on emphasis in other Arabic dialects (e.g., Al-Ani 1970; Yeni-Komshian et al 1977; Bukshaisha 1985; Hussain 1985;

Norlin 1987; Al-Nuzaili 1993). In fact, in some of the available studies, the researcher was the only subject, e. g., Al-Nuzaili's (1993); VOT results were based on his own speech only. In other studies, the informants employed were asked to speak standard Arabic rather than their own dialect (Yeni-Komshian et al 1977; Yeou 1997). The subjects in this study were linguistically naïve. They were asked to use their own dialect since it is well-known that standard Arabic differs from spoken dialects. Standard Arabic represents the formal language used by educated people and in the media in all Arab countries while the informal dialects are used for everyday commutation in different Arab countries (Mitchell 1962; Mansouri 2000; Gadalla 2000) (see chapter two, section 2.1 for more details).

Some researchers like Port et al (1980) have used informants with different dialects (in this case: 2 Egyptians, 2 Iraqis and 1 Kuwaiti). Since there are expected phonological, morphological and syntactic differences between dialects, this may influence the target words that are chosen by the researcher as they would have to be common across dialects and may therefore be standard Arabic lexical items. Using speakers of different dialects can therefore provide inconsistent results since each speaker may be influenced by his native dialect and manifest some features of his own dialect. In order to avoid the potential problems listed above, the origin of all speakers in this study is the city of Zliten where they currently live.

Each prospective informant was asked to provide information about their age and foreign language experience. Most of the participants had dialectal contact with Arabic dialects spoken in other countries through the media, e.g., TV or radio, or contact with other Libyan dialects through friends, trade and study. Most of the subjects also had foreign language experience with English, which varied depending on the level of education (see Table 3.1). While the subjects differed in their foreign language experience, this study did not set out to examine the potential influence of this factor on emphasis production. All the subjects are university-educated, but some of them are post-graduate students. Yet, correlation between individual differences and education is not expected since the level of education is fairly controlled for.

Table 3.1. Age and foreign language experience for the participants in this study

		Experience with foreign language in years			
speakers	age	preparatory	secondary	tertiary	postgraduate studies
1	34	1	3	1	1
2	34	1	3	2	-
3	40	3	0	2	1
4	39	3	3	3	2
5	31	0	3	2	-
6	30	1	3	2	1
7	32	0	3	1	-
8	31	0	3	2	-
9	35	2	3	4	1
10	36	3	3	2	-
11	30	1	3	1	-
12	33	0	3	1	-
13	27	3	3	1	-
14	35	2	3	1	-
15	34	1	3	1	-
16	35	2	3	1	-
17	39	3	3	0	-
18	33	0	3	1	-
19	37	3	3	1	-
20	33	0	0	1	-

Fifteen speakers were recruited in Libya and five speakers in the UK. While these five speakers were pursuing their postgraduate studies and may have more contact with English than the Libyan-based speakers, care was taken in choosing informants who spoke the target dialect and who had spent the least time in the UK in order to reduce, as much as possible, the effect of any language transfer from the foreign language to their own dialect. These speakers replaced five speakers recruited in Libya due to their recordings not being good enough to be used for the acoustic analysis. Apart from this, all the twenty speakers had lived in Zliten since birth.

3.3. Material

The emphatic consonants used in this study were /dˤ tˤ sˤ/ and their plain counterparts /d t s/, followed by the vowels /iː ɪ eː uː ʊ oː ɛ æː/. This study focused on the emphatics /dˤ tˤ sˤ/ since these emphatics are used in the dialect investigated although for some speakers or areas within the Tripolitanian dialect /dˤ/ is realised as [ðˤ]. The emphatic /zˤ/ has a limited occurrence as it is used instead of /dˤ/. Furthermore, the emphatics /dˤ tˤ sˤ/ occur in all vocalic contexts and they have non-emphatic counterparts. The emphatic /lˤ/ and other so-called primary emphatics are excluded. Although Laradi (1983) classified /lˤ/ as a primary pharyngealised emphatic, she made it clear that this emphatic has limited distribution and occurs in a limited number of words like the word Allah (God) and its derivatives. As for other emphatics like the so-called secondary emphatics like /ḅ ṃ ṇ/, there is dispute over their emphaticness. Abumdas (1985) attributed emphasis to the low back vowel in their context particularly if considering that they occur only in the context of the low back vowel.

The vowels used in this study are reported to be present in a number of Libyan dialects; these dialects include ZA (Abumdas 1982), DA (Aurayieth 1982), and SA (Botagga 1991) TLA (Laradi 1972, 1983; Muftah 2001). The target data consisted mainly of monosyllabic words with initial plain or emphatic consonants in a CVC syllable structure; however a disyllabic CVCV structure was used for /d/ and /dˁ/ in the vocalic context of /oː/ as shown by the words /doːxa/ (state of being unconscious) and /dˁoːga/ (something to taste) (see appendix 10a). This was because of the difficulty in finding a CVC word that contained the emphatic /dˁ/ in the vocalic context of /oː/.

As studies on the acoustic features of emphasis have not been conducted for Libyan Arabic, the choice of the sample was carefully considered so as to be focused and restricted. Therefore, focus was on mono-syllabic words in initial positions. The fact that this study also focuses on a number of acoustic measurements may require restricting the context so that it is possible to allow for an opportunity to discuss results for different acoustic patterns of emphasis and to compare results from this study with those from Arabic dialects. Most acoustic studies focused on the emphatic consonants in initial positions (e.g., Kuriyagawa et al 1988; Al-Nuzaili 1993; Heselwood 1996; Yeou 1997; Al-Bannai 2000; Khattab et al 2006). There was a preference for the use of minimal pairs whenever possible, but in some cases, where it was not possible to find them, near minimal pairs were used instead. It was also not possible to find target words with initial /sˁ/ followed by /ɪ/; therefore this particular context was not included in the material.

Each of the emphatic consonants /dˤ tˤ sˤ/ and their non-emphatic counterparts were represented by one example word in each vocalic context and each word was repeated three times, so each speaker produced a total number of nine tokens for the plain context and nine for the emphatic context for each of the eight vocalic contexts.

3.4. The recording procedure

The recordings were made using Edirol Rl Wave/MP3 recorder with Audio Technica ATR 25 microphone and a Prefer MB-8 microphone amplifier. The Edirol was set to PCM (WAV) 16 bit 44.1 KHz. The recorded data was first saved on the Edirol recorder and later transferred onto a personal computer on which the software used for the acoustic analysis was installed.

Some procedures were taken before the start of recording. All informants reported having normal speaking and hearing abilities. Fifteen speakers were recorded in Libya in a quiet place while the other five speakers were recorded in the UK in a recording room in the school of Education, Communication and Language Science at Newcastle University. All the informants were asked to examine the word list to check their familiarity with all words and their ability to produce them. They were also asked to adopt a moderate speaking rate and the microphone was placed about 20-25 centimetres away from their mouths. The participants were not aware of the purpose of the study. They were told that the researcher was interested in obtaining some utterances in their dialect. The target words were organised in a way that the examples containing the plain consonants were not necessarily preceded or followed by those containing their emphatic counterparts.

The citation forms of these words were inserted in a carrier sentence which was the same for all target words. The carrier sentence was /gu:lɪ......marte:n/ (say.....twice). The carrier sentence along with the target words were written in Arabic script. The instructions were given in Arabic to read the target utterances without pausing between words within the same sentence. Pauses between words in the same carrier sentence were expected to affect the speaking rate and accordingly some measurements like duration and formant frequency patterns. The target utterances were presented on ten sheets and the subjects read them one by one. The start and the end of the sheet included fillers in order to avoid any possible effects on intonation, duration and loudness associated with utterances preceding or following a pause.

Short breaks were given after reading each sheet and subjects were also given time during the break to double-check the next sheet before resuming the recording task. After the first repetition, subjects took a long break of about 20 minutes and then they started the second repetition and so on.

The informants were asked to use their own dialect and were asked to avoid being misled by the Arabic script which might have led them to use a standard Arabic style of speech. Dialectal variants were included in the orthography in order to encourage the subjects to use a non-standard style (e.g. /gu:lɪ/ for standard Arabic /qu:lɪ/). However, some subjects unintentionally produced some dialectal words with a standard Arabic pronunciation. In such a case, recording was stopped and repeated.

3.5. The auditory analysis

Auditory analysis of the vowels in the plain and emphatic context was conducted in order to categorise the allophones in both contexts. This was a categorical rather than a gradient analysis as the focus was to distinguish the allophones in the plain context from those in the emphatic context; it is not a fine-grained description of the allophones of the vowels in both contexts. Therefore this may be one of the reasons why the variability observed in formant frequency patterns does not align with the auditory analysis conducted in this study (see chapter 4, section 4.6). The results of the auditory analysis are presented in appendix 4.

3.6. Acoustic measurements

The software Praat (Boersma and Weenink 2007) was employed to take measurements directly from spectrograms and waveforms. Acoustic measurements were elicited manually from tokens. The default settings of Praat were used (see Table 3.2) and were modified whenever necessary.

Table 3.2 The default settings of Praat used in the acoustic measurements.

formant settings				
maximum formant (Hz)	number of formants	window length (s)	dynamic range (dB)	dot size (mm)
5000.0	5.0	0.025	30.0	1.0
spectrogram settings				intensity settings
view range Hz)	window length (s)	dynamic range (dB)		view range (dB)
0.0-5000.0	0.005	50.0		50-100

Measurements were taken from 2760 tokens (see Table 3.3) and the study focused on a variety of acoustic measurements (see Table 3.4). The sections below describe the procedures followed in extracting each of the acoustic measurements.

Table 3.3. Number of tokens recorded per speaker and the total number for all speakers

consonantal context	vocalic contexts	number of repetitions	no. of tokens	
/t/	8	3	24	tokens per subject 138
/ṭ /	8	3	24	
/d/	8	3	24	tokens for all subjects 138*20 =2760
/ḍ/	8	3	24	
/s/	7	3	21	
/ṣ/	7	3	21	

Table 3.4. Number of acoustic measurements taken for this study

F1 onset	F1 mid	F2 onset	F2 mid	F3 onset	F3 mid
2760	2760	2760	2760	2760	2760
vowel duration	fricative duration	fricative intensity	VOT for /t/ and /tˁ/	CD for /t/ and /tˁ/	total number of measures
2760	840	840	960	960	22920

3.6.1 Formant frequency measurements

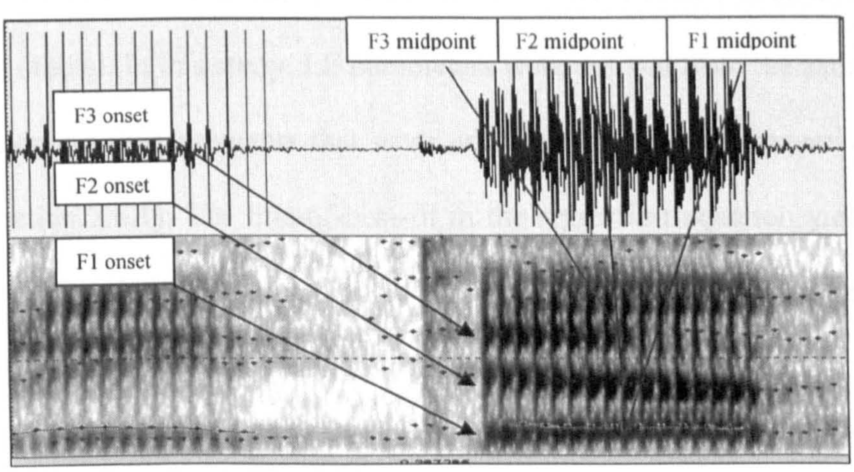
The first three formant frequencies were measured in Hertz at both the vowel onset and the vowel midpoint of eight vowels following the plain and emphatic consonants (more details on locating onset and midpoint are found later in this section). This was to explore how vowels of different qualities and lengths were affected by emphasis. Measuring these three formant frequencies was motivated by results from acoustic studies on emphasis in different Arabic dialects. Emphasis could affect either F2 (e.g., Norlin 1987; Bin-Muqbil 2006), F1 and F2 (e.g., Giannini and Pettorino 1982; Khattab et al 2006) or the first three formant frequencies (e.g., Yeou 2001; Jongman 2007 et al). This study included the three formant frequencies to assess such an effect in Libyan Arabic and reveal how this effect could reflect the emphatic consonant's secondary articulation, particularly if considering the different realisations of this secondary articulation across different dialects and studies (see chapter 2, section 2.4.2).

The onset of the vowel is the closest part of the vowel to the preceding consonant, so measuring such a point is expected to reveal the greatest degree of effect the consonant could have on the following vowel. Measuring the midpoint is also important given that this point may be the least affected point if considering that it is equally away from the initial and final consonant (Lindblom 1963b; Lehiste and Peterson 1961). Yet the effect of emphasis is known to extend to vowel midpoint, and to decrease as compared to that on vowel onset (Jongman et al 2007). Furthermore, acoustic information for formant frequencies at both the onset and midpoint are helpful in encoding information about CV coarticulation as F2 results from this study are utilised to elicit locus equation parameters. Thus measuring both points is a justifiable requirement that provides an inclusive picture of the effect of emphasis on formant frequency patterns.

The onset of the vowel was determined as the start of the energy representing formant frequencies at the very beginning of the vowel in the spectrogram and the start of the periodic soundwave of the vowel. Measurements of the onset of the first three formant frequencies accordingly were taken at the first pitch period of the vowel following the plain and emphatic consonants. Generally speaking, all three formant frequencies were measured at the same point. In cases where one formant frequency appeared later than the others, a compromise was reached to measure the onset of the three formant frequencies on the same point whenever the delay was slight, allowing for this point to include all the onsets of the three formant frequencies. In cases where the onset of one formant frequency starts later than the others and the delay was long, this formant frequency was measured separately.

The midpoint was the point in the middle of the vowel, which normally follows the transition between the vowel and the consonant (see Figure 3.2) (Rosner and Pickering 1994; Frieda et al 2000). The vowel midpoint was determined by dividing the whole vowel duration by two, and the formant frequencies were measured at the point that divides the vowel into two halves. Vowel duration was identified by measuring vowel duration from F2 onset to F2 offset. The soundwave was also examined to ensure that the periodic soundwave, signalling the start of the vowel after the consonant has started. All three formant frequency midpoints were measured at the same point.

Fig. 3.2. The measuring points for formant frequencies



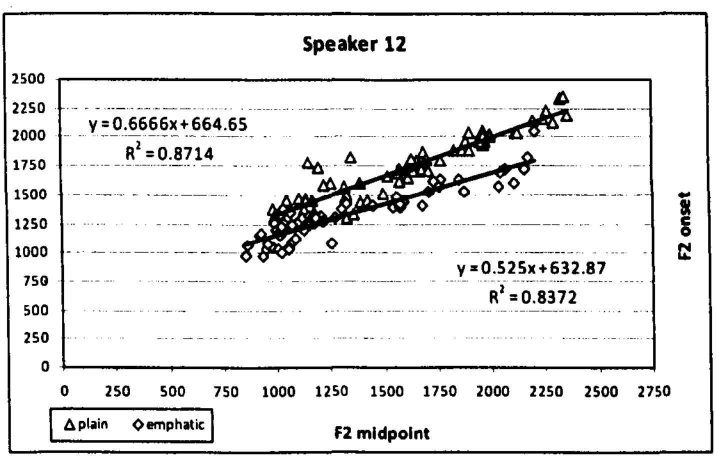
Formant frequencies were measured using the automatic formant tracker option in Praat, but visually monitoring the tracker to look at individual measurements where the tracker was incorrect. It was also necessary to change the number of formant frequencies being displayed through the option "formant settings" in Praat. This change depended on vowel quality as it was appropriate to set the number of formant frequencies at five for high and front vowels and at six for back and low vowels in order to obtain the most accurate formant frequency readings in the spectrogram as the formant tracker becomes more representative of the actual formant frequency on the spectrogram.

3.6.2 Calculation of locus equation parameters

LE parameters were quantified by plotting F2 onset along the y axis and their corresponding F2 midpoint along the x axis according to the method employed by Lindblom (1963a) in which an LE straight line regression was fitted to data points. This method of calculating locus equation was also used in a number of studies (Neary and Shammass 1987; Krull 1987, 1988, 1989; Sussman 1989; Matthews 1990; Sussman 1994; Sussman et al 1991; Sussman et al 1993; Sussman et al 1995; Sussman and Shore 1996l; Sussman et al 1998 among others). In this study, LE parameters were derived from the same F2 onset and midpoint measurements that were used for the formant frequency analysis (see section 3.6.1). The line-of-best-fit in the regression equation yielded slope, y-intercept and R^2 values (see Figure 3.3). The slope of the regression line indicates the extent of the change that occurs in the predicted value y (F2 onset) for each one point change in x (F2 midpoint). Y-intercept refers to the point at which the regression line crosses the y axis. R^2 shows the degree of the overall variability in y (i.e. F2 onset) that has been predicted by the variable x (i.e. F2 midpoint). An R^2 value of 1.0 indicates that x and y are highly correlated and 100 % of the total degree of variation in y has been predicted by x while an R^2 value of zero is indicative of no correlation between x and y and there is no possibility of the variation in y to be predicted by x.

Thus LE is important in encoding information about CV coarticulation based on acoustic measurements of two points, namely F2 onset and F2 midpoint. This acoustic examination of coarticulation is triggered by articulatory differences between the plain and emphatic consonants, as the emphatic consonants are characterised by the presence of the secondary articulation responsible for the acoustic changes accompanying the production of this class of Arabic consonants. This is also supported by acoustic analysis which shows that in LA the plain and emphatic consonants have opposing impacts on formant frequency patterns, particularly F2 (see Chapter 4). LE parameters are computed for all data, each speaker and each consonantal type.

Fig. 3.3. The LE regression line for the plain and emphatic contexts



3.6.3. Durational measurements

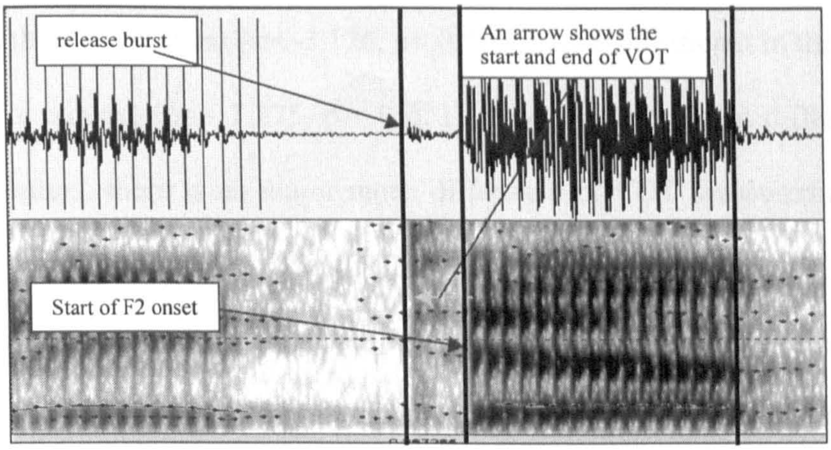
There is argument in the literature concerning the effect of emphasis on some durational parameters. Some researchers indicate that the emphatic context is associated with longer duration than the plain context while others disagree with this view (see Chapter 2, section 2.5.3). Furthermore, it is reported that the vowel in the emphatic context is longer than that in the plain context. Therefore, in this study, a number of durational parameters are measured in order to assess the effect of emphasis on these parameters. These include closure duration and VOT for /t/ and /ṭ/, the duration of the vowel in the plain and emphatic contexts, and the fricative duration for /s/ and /ṣ/. Measuring closure duration could show the effect of emphasis on CD and the relation between closure duration and other acoustic parameters like VOT and vowel duration. The VOT investigation would show the effect of emphasis on the timing of voicing and how this timing is controlled by physiological factors related, for instance, to the degree of glottal opening.

CD and VOT were not measured for the voiced /d/ and /ḍ/ since VOT was not found to distinguish the voiced emphatic /ḍ/ from its plain counterpart in some Arabic dialect, e.g., Lebanese Arabic (Yeni-Komshian et al 1977), Yemeni Arabic (Al-Nuzaili 1993) and Libyan Arabic (Kriba). Results from these studies showed that the VOT for both /d/ and /ḍ/ is associated with voicing lead and there is a considerable overlap between the VOT values of /d/ and /ḍ/. Generally speaking, studies on Arabic have tended to focus on the effect of the voiceless emphatic /ṭ/ on CD and VOT rather than that of the voiced emphatic /ḍ/ (see chapter two, sections 2.5.2 and 2.5.3). Although the discussion in section 2.5.2 shows that the back constriction associated with the production of the emphatics affects the laryngeal activities, this seems to be better observed for the voiceless emphatics. The differences in the VOT value between /t/ and /ṭ/ cause differences in the closure duration as a result of a temporal relation. This effect might not be manifest in the voiced emphatic consonant.

The general procedure adopted in obtaining the duration (for CD, VOT, VD and FD in milliseconds) was to select the portion to be measured and use the duration reading from Praat or to highlight the relevant portion and obtain the duration from the option "Get selection length" in Praat. Expanded views of the sound file were made by zooming into various portions to closely observe the boundaries between the segments in the spectrogram and waveform. This general procedure was followed after determining the boundary of the acoustic parameter to be measured from the soundwave and the spectrogram as discussed later in this section.

The start of VOT for /t/ and /tˤ/ was measured from the release burst to the start of F2 onset following the procedure adopted by Klatt (1975) (see Figure 3.4). The release of the stop was marked spectrographically by an abrupt change in overall spectrum (Lisker and Abramson 1964). The end of VOT was marked by the start of the energy of the second formant frequency on the spectrogram and the start of the periodic waveform which signalled the start of the vowel (more details on how F2 onset is identified, see section 3.6.1 in this chapter).

Fig. 3.4. VOT measurement from release burst to F2 onset



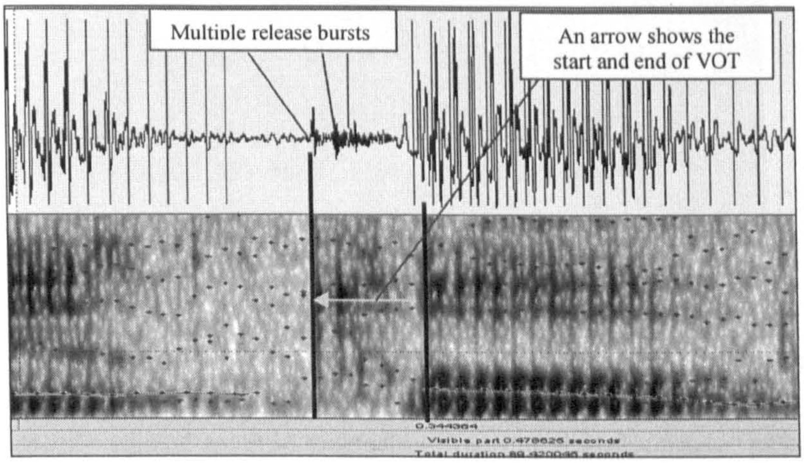
Most studies on different Arabic dialects (Shaheen 1979; Bukshaisha 1985; Al-Nuzaili 1993; Heselwood 1996; Kriba 2004; Khattab et al 2006; among other) followed the traditional way of identifying VOT as the duration between the release burst and the start of voicing (Lisker and Abramson 1964). There was however a justifiable reason for preferring Klatt's (1975) approach to measuring VOT to that suggested by Lisker and Abramson (1964). This was because a problematic issue was encountered when measuring the duration of the following vowel in case Lisker and Abramson's (1964) approach was considered. Given that the duration of the vowel following /t/ and /tˤ/ was measured from F2 onset to F2 offset in this study, measuring VOT from the release burst till the start of voicing would have left a gap as the part of the utterance from the start of voicing to F2 onset would not be measured. This, in turn, could also have affected the VOT results from this study, particularly when compared to those from other dialects. For this reason, comparison was made between results from the two approaches (see Table 3.5) given that the start of voicing following the release burst may appear on the spectrogram before the onset of F2. According to the non-parametric version of the independent sample t-test, Mann-Whitney, the difference between results from the two approaches was only significant in the case of the plain context ($z = -3.126$, $p < .0.5$) and non-significant in the case of the emphatic context ($z = -1.275$, $p > .05$). Despite this significant difference in the plain context, there is no major mean difference in VOT measurement between the two approaches. Thus adopting Klatt's (1975) approach in this study is not expected to affect comparing the VOT results from this study with those from other Arabic dialects which adopted Lisker and Abramson's (1964) approach.

Table 3.5. Two approaches to measuring VOT (Mean VOT in milliseconds)

Approach	Klatt (1975)		Lisker and Abramson (1964)	
Vowel	t	tˤ	t	tˤ
/iː/	51	21	48	20
/ɪ/	35	20	33	19
/eː/	35	17	33	18
/oː/	32	15	30	15
/ʊ/	35	18	33	18
/uː/	33	19	32	19
/ɛ/	30	17	28	16
/æː/	30	16	28	15
Overall mean	35	18	33	17

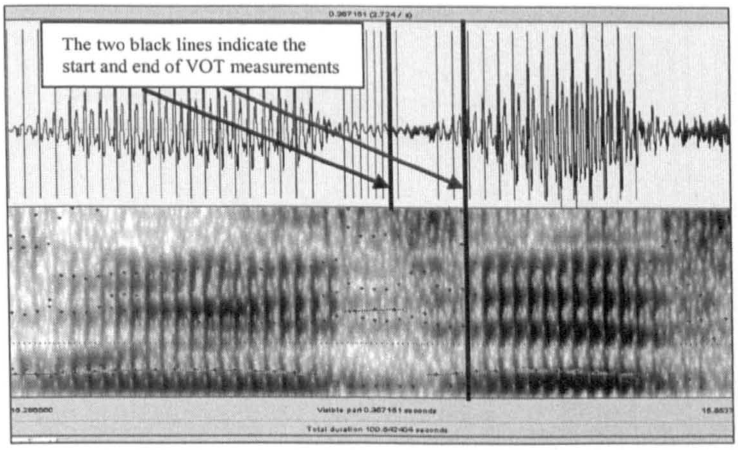
Both spectrograms and waveforms were used for the identification of VOT. The waveform was helpful particularly when there was more than one release burst or when the release phase was not clear on the spectrogram. As shown below, although there was more than one burst, the first one on the left was chosen to be indicative of the start of VOT since it seemed to be the clearest one and the noise in the waveform started with the first burst. Cho and Ladefoged (1999) considered the last burst as the starting point for VOT measurement whenever there were multiple bursts. However, this study measured VOT from the first burst when double or multiple bursts occurred. This was also adopted by Azou et al (2000), particularly when the release burst was followed by noise in the waveform (see Figure 3.5).

Fig. 3.5. Multiple release bursts



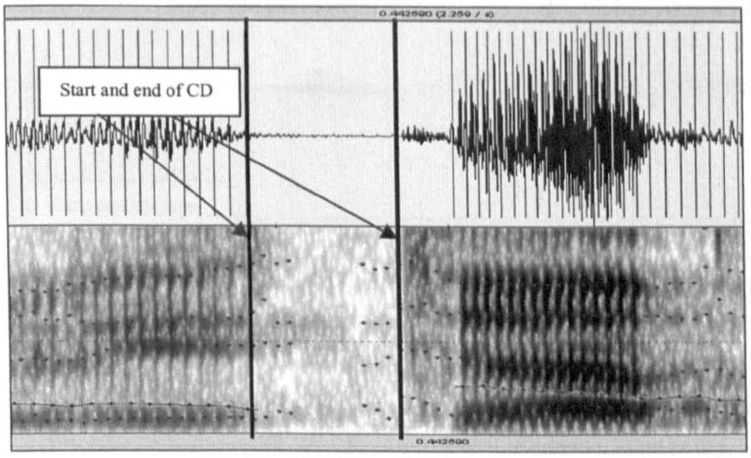
As illustrated in Figure 3.6, the spectrogram did not always provide clues about how to determine the release burst and there did not always seem to be an obvious separation between the closure phase and VOT. This resulted at first in some kind of confusion with respect to the point that could mark the start of VOT since there was no apparent transient even in the waveform. However, the waveform was more reliable than the spectrogram in identifying the start of VOT. The waveform displayed some noise in the form of concentrated energy corresponding to the period of voicelessness that was indicative of VOT. VOT was measured from the start of this acoustic energy till F2 onset (see Figure 3.6). The changing energy in the spectrogram was also helpful as the VOT interval was marked with more concentrated energy than the preceding closure period.

Fig. 3.6. A case where determining the start of the release is based on the waveform



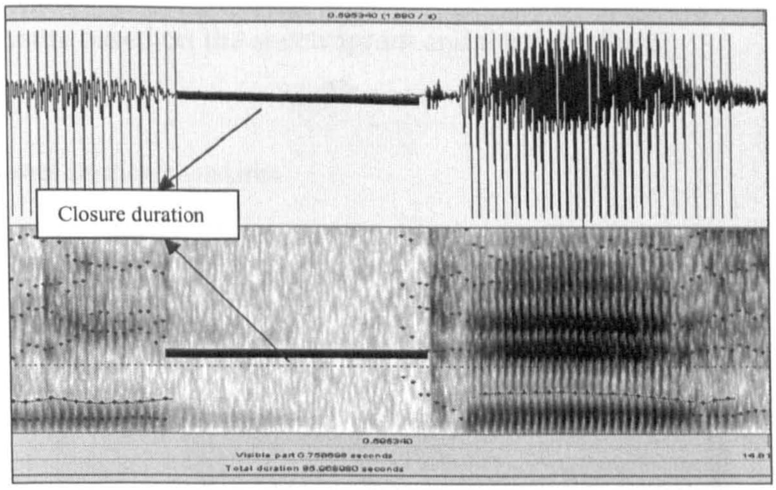
Closure duration for /t/ and /t̪/ was measured from the F2 offset of the preceding vowel to the beginning of the release burst (see Figure 3.7) following Cho and McQueen (2005). The stop was preceded by a vowel so the beginning of the closure interval was marked at the point where the second formant frequency ended. The right edge of the closure interval was marked at the beginning of the stop release. As illustrated in Figure 3.7, the almost flat line in the waveform represented the closure duration which was followed by irregular perturbations corresponding to the stop burst that was caused by the release of the stop closure (see Ladefoged 2003). The portion of the spectrogram corresponding to this flat line in the waveform displayed no activity as it was characterised by silence although there were traces of formant frequency shadows. In cases where F2 offset was not clear and just showed formant frequency shadows on the spectrogram, the identification of the start of the closure was also signalled by the total absence of acoustic energy during the silence gap following Lisker and Abramson (1964).

Fig. 3.7. The start and end of closure duration



In some cases, closure duration measurement was associated with a long silent period which might be caused by the speakers' delay in producing the carrier sentence continuously without any pauses between words within the same sentence. For this reason those seemingly exaggerated tokens were excluded. Kent and Read (1992) suggested some criteria for identifying the closure duration which they referred to as the stop gap. The stop gap, according to them, was characterised by a region of reduced energy and a silence period of about 50 to 150 ms. Therefore any period which exceeded this limitation was regarded as being exaggerated and excluded (see Figure 3.8). The decision regarding the exclusion of some tokens also depended on listening carefully to these tokens to find out whether it was possible to detect a pause. For instance, the closure duration for the token in figure 3.8 sounded unusually long as through listening to this token a pause between the target word and the preceding word was detected.

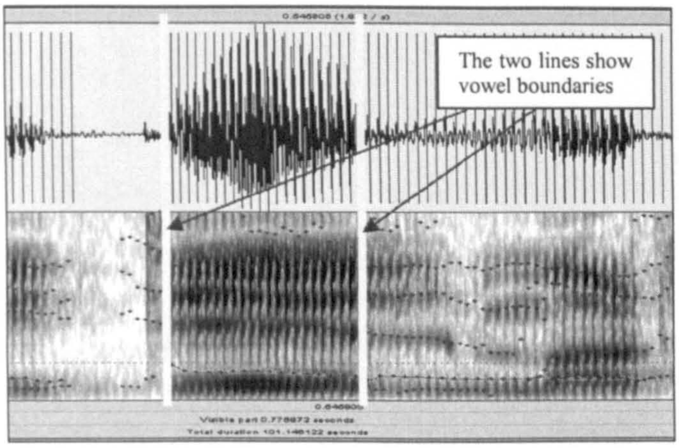
Fig. 3.8. Unusually long closure duration (about 202 ms)



The vowel duration in the plain and emphatic contexts was also measured to investigate the effect of emphasis on the duration of the following vowel. The vowel duration was measured from F2 onset to F2 offset (see Figure 3.9) since F2 signals vowel boundaries (Flege and Port 1981). F2 onset was identified spectrographically as the start of the first vertical striation extending upward through the frequency regions of F2 with no interruption till the end of the second formant frequency which marked F2 offset. It was also obvious that in the spectrogram the formant frequency patterns were darker for the vowel than for the preceding and the following consonants and this distinguished the vowel from these consonants.

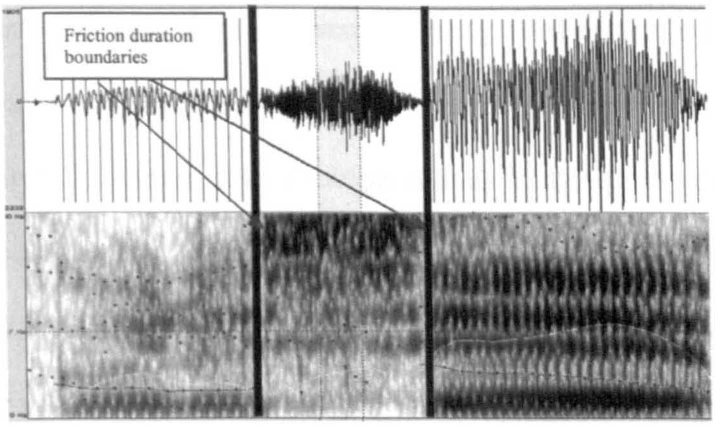
The waveform was also visually inspected especially when there was a difficulty in determining the boundary between the vowel and the consonant. For instance, the waveform was helpful in this respect as it clearly showed the periodic soundwave of the vowel and separated the vowel from the adjacent consonants. Furthermore, the researcher highlighted the portion corresponding to the vowel and listened to it several times in order to have auditory support for the measurements based on the spectrogram and the waveform.

Fig. 3.9. Vowel duration boundaries



Duration measurements were also taken from the fricatives /s/ and /sˤ/ (see Figure 3.10). The duration of the emphatic /sˤ/ is thought to have a longer duration than its plain counterpart as a result of the greater intensity for /sˤ/ than for /s/ (see the following section). The friction duration was taken from the onset of aperiodic soundwave that signals the start of the fricative (just after the periodic waveform of the preceding vowel) to the onset of the periodic sound wave of the following vowel. From the spectrogram, the fricative was also identified from the start of the fricative noise to F2 onset of the following vowel. The fricative noise was indicated by high frequency energy displayed in the spectrogram.

Fig. 3.10. Duration measurements of /s/ and /sˤ/

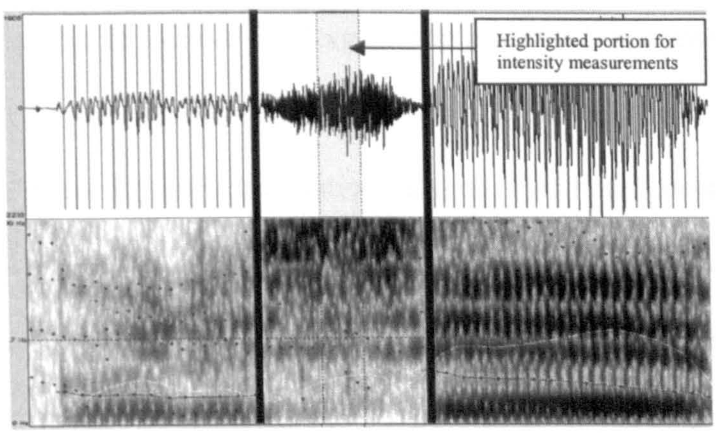


3.6.4. Intensity measurements of /s/ and /ṣ/

The intensity for /s/ and /ṣ/ was also measured as part of investigating the relation between intensity and duration; in light of literature, the emphatic /ṣ/ is thought to have greater intensity and accordingly longer duration compared to its plain counterparts /s/ (see chapter 2, section 2.5.3 for more details about the relation between intensity and duration). Thus measuring the intensity of /s/ and /ṣ/ was carried out to find out whether there were any intensity differences between /s/ and /ṣ/ to relate results from intensity to those from duration measurements.

The procedure adopted in intensity measurement involved highlighting the middle 25% of the fricatives /s/ and /ṣ/ and obtaining the mean intensity values for this portion (see Figure 3.11). The intensity value was obtained from the option "get intensity" in Praat after highlighting the relevant portion. This provided the mean intensity value for the selected portion. The reason behind this was to reduce any effect that might be caused by the adjacent segments and to focus on measuring a sufficient portion that represents the intensity of the fricative consonants under investigation. This is an absolute intensity measurement. The intensity measurement is regarded as a relative measure as a certain sound displays an intensity of many varying intensities (Ladefoged 2001). The intensity of a certain sound (target sound) is measured relative to another reference sound (through comparison of the relative amplitudes of the two sounds) which has the highest amplitude in the utterance (Ladefoged 2003). There is also a comparison between the relative powers of the two sounds.

Fig. 3.11. Intensity measurements of /s/ and /sˤ/



3.7. Statistical analysis

The statistical analysis for the current study was conducted using the statistical software "SPSS for windows". A number of statistical tests were applied; these tests include the independent sample t-test, one way Anova, factorial Anova and post hoc tests. Both parametric and non-parametric tests were applied. The parametric tests were applied when normality and homogeneity of variance assumptions are met. Otherwise, either the data was transformed so as to satisfy these assumptions and apply a parametric test or equivalent non-parametric tests were adopted. Therefore, it is necessary to ensure that the data is parametric (i.e., the assumptions are met) if a parametric test is to be applied; otherwise, there is a possibility to obtain inaccurate results (Field 2009). Pre-tests were conducted to check whether the data were normally distributed around the mean for each group and whether the compared groups have equal variance. For normality of distribution, two tests were applied according to the instructions provided by SPSS. If the cases are more than fifty, the Kolmogorov-Smirnov test is used, and if they are less than fifty, the Shapiro-Wilk test is used. Field (2009) also indicates that the accuracy of the Shapiro-Wilk test can be influenced by large samples. The homogeneity of variance between the compared groups is checked using the Levene test.

The normality of distribution and/or the homogeneity of variance assumptions are not met in the case of F1 onset, F2 onset F3 onset, F1 midpoint, F2 midpoint and F3 midpoint. So the data were transformed. A number of transformation tests were conducted (e.g., log transform, square root, Blom, Tukey, Rankit). The test that was successful in transforming F1 onset, F3 onset, F1 midpoint and F3 midpoint so as to meet the normality and equal variance assumptions was the Blom test, but not in transforming F2 onset and F2 midpoint. The decision was to conduct Anova even in the cases where these assumptions are not met. This is because factorial Anova has no parametric equivalent (Field 2009). Anova is a robust test and if there is departure from these assumptions, the results can still be accurate (Field 2009). Furthermore, as the parametric assumptions are not met for y-intercept, VOT and vowel duration, the data are transformed using the Blom test since post hoc test were applied, and there are no non-parametric tests for post hoc tests. Finally in the statistical results reported in the following three chapters, applying a parametric test means that the parametric assumptions are met and applying non-parametric tests means that the assumptions are not met. In appendix 3, the shaded boxes indicate that the test conducted is non-parametric.

T-tests are used to test if two groups differ. T-tests have two variables; a dependent variable (the measure) and an independent variable with two levels (plain and emphatic). The independent sample t-test is applied in this study to compare the plain and emphatic contexts for formant frequencies and VOT in difference vocalic contexts, slope, y-intercept, closure duration, fricative duration, fricative intensity and total CV duration. The independent sample t-test is used when comparing two different groups, e.g., plain and emphatic. Instead of t-test, Anova is used to compare vowel duration in the emphatic context with the duration of the same vowel in the plain context. This is because the mean difference between the two groups is small and Anova is more robust than t-tests.

In the analysis of formant frequency results, one way Anova, two way Anova and post hoc tests were applied. One way Anova was applied to find out the main effect in situations where there is one continuous variable referred to as the dependent variable and one categorical variable with two or more groups referred to as the independent variable. For instance, in this study each formant frequency measurement (e.g., F1 onset) is the dependent variable and subject is the independent variable with 20 speakers. One way Anova tests the probability that the groups (speakers) differ from one another. The same applies to different vowel contexts and different consonantal types.

Factorial Anova with two levels (two-way Anova) was applied because in some cases there is more than one independent variable. In this case, the factorial

Anova has the advantage of testing the interaction between factors (independent variables). As there is more than one independent variable, there is a chance of interaction between the variables. An interaction happens when one level of a variable affects the levels of a second variable in a different way. In the analysis of formant frequencies, the dependent variable is F1 onset, F2 onset, F3 onset, F1 midpoint, F2 midpoint or F3 midpoint while the independent variable is plain*emphatic. One of the questions that this study seeks to answer is how the first three formant frequencies differ between the plain and emphatic contexts. However, as this study uses three plain and emphatic consonants of different types, a number of 20 speakers, eight vocalic contexts, each of these can be considered as another independent variable along with the plain-emphatic distinction when a two way Anova is applied. It is clear that each independent variable can have two or more levels. The effect of the emphatic context on formant frequencies as compared to the plain context may be affected by the consonantal type, speaker variability, and/or vowel quality; therefore there may be an interaction between the effect of emphasis on formant frequencies and consonantal type, speaker and/or vowel quality.

Anova is also used to compare the slope and y-intercept differences across different consonantal types. Bonferroni post hoc tests are applied to find out the differences between each consonantal group. Bonferroni is a powerful test when the number of mean comparisons is small, but when they are large, the Tukey post hoc test is preferred (Field 2009).

3.8. Reliability of acoustic measurements

Reliability was achieved in eliciting all measurement for this study through consistency of the measuring procedure and repetition of the measurements as suggested by Bryman (2001). The approach described in this chapter for measuring all the acoustic parameters investigated in this study was consistent. The researcher repeated the measurement for all tokens immediately after taking all measurements to allow for comparison of the two measurements. In case the two measurements differed considerably, a third measurement was taken to decide on the correct measurement and ensure accuracy of the measurement. Moreover, any measurement which was noticeably and considerably high or low compared to the mean values and with other tokens was checked for accuracy.

In order to show the reliability of formant frequency measurements, 10% of the checked measurements are presented in appendix 11. The measurements were taken manually and the same procedure as that adopted for the first measurement was followed (see section 3.6.1). First the researcher started with the first repetition for each speaker, one by one. The choice of this sample is based on measuring the second token from each ten tokens according to the order of recording (see shaded boxes in appendix 10b). The total number of the tokens is organised according to the order of recording. When measurements of the first repetition of the first speaker are finished, dealing with those of the second speaker is continued and so on till the last speaker. Care was taken to ensure that the second token from a group of ten is always measured. As the total number of the recorded tokens is forty six, the first token of the second speaker was considered as number forty seven and the same procedure was followed when starting with the tokens of the other speakers. In case a token was excluded due to bad recording or mispronunciation, this token was not counted. The same procedure was followed when measuring the second and third repetitions.

Most tokens displayed similar or the same formant frequency values. However, there can be some differences between the values of the first measurement and that of the checked measurement (see shaded boxes in appendix 11). The boxes are shaded when the F1 difference is more than 10 Hz, the F2 difference is more than 50 Hz and the F3 difference is more than 100 Hz.

3.9. Summary of chapter three

This chapter described the procedure carried out in collecting the data required for this study in terms of the dialect, material and informants used in addition to the organisation of the recording procedure, the software employed for making the acoustic measurements and how these measurements were made. All this paves the way for the analysis of the results, which are presented in the following three chapters.

Chapter Four

Formant Frequency Results

4.0. Introduction

This chapter is concerned with the effect of the emphatic consonants on the first three formant frequencies at the onset and midpoint of the following vowels. An auditory analysis is also conducted to explore the quality of vowel allophones in the plain and emphatic contexts and whether these allophones correspond to changes in formant frequencies patterns. This section also sheds some light on speaker variability and the effect of the consonantal context on formant frequencies.

4.1. Auditory analysis of vowel allophones

An auditory analysis of vowels in the plain and emphatic contexts is presented in this section before discussing the effect of emphasis on formant frequency patterns. There are auditory differences between the vowels in the plain context and the vowels in the emphatic context (see Table 4.1 for the most frequent allophones and appendix 4 for a detailed auditory analysis). On the whole, the auditory impression seems to support acoustic results as the effect of emphasis is manifest in formant frequency patterns of the following vowel.

The short vowel /ɪ/ undergoes considerable backing and lowering under the influence of the emphatic consonant. In the emphatic context, the allophonic variation of short plain /ɪ/ includes a centralised [ɨ]. The backing of the short /ʊ/ is enhanced in the emphatic context and /ʊ/ is realised as [ʊ̞]. The allophonic change between vowels in the plain context and vowels in the emphatic context is more obvious for low vowels /ɛ/ and /æ:/ than for other vowels. Short /ɛ/ and long /æ:/ become retracted and slightly lowered in the emphatic context. The auditory impression of these vowels changes completely in the emphatic environment, resulting in the vowel allophones [ʌ] and [ɐ̞] respectively.

Table 4.1. Auditory analysis of vowel allophones in the plain and emphatic contexts

vowel phoneme	/i:/	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
plain allophone	[i:]	[ɪ]	[e:]	[o:]	[ʊ]	[u:]	[ɛ]	[æ:]
emphatic allophone	[ɨ̞:]	[ᵻ]	[e̞:]	[o̞:]	[ʊ̞]	[u̞:]	[ʌ]	[ɐ̞]

The auditory impression shows that for the vowels /ʊ u: o:/ in the emphatic environment, backing is enhanced. For the vocalic context of /i:/ and /e:/ where the effect of emphasis is more prominent at vowel onset than at vowel midpoint, the auditory analysis still leads to the perception of these vowels as [i:] and [e:] although the effect of emphasis is perceived. This may be due to the partial effect of emphasis on the vowel onset of long vowels. Although the effect of emphasis can be traced at the midpoint, it is not very considerable. Duration plays an important role in determining how emphasis influences the adjacent vowel particularly for vowels with front and high articulations.

4.2. General formant frequency patterns

In order to explore the effect of emphasis on formant frequencies of the following vowels, the formant frequencies of vowels in the emphatic environment are compared with those of vowels in the plain environment. Although the vowels in the plain context may not represent the neutral context of vowels in isolation, comparing formant frequencies of vowels in the emphatic context with those of vowels in isolation would not be a meaningful comparison since vowels rarely occur in isolation. Therefore in this study the vowels in the plain context are regarded as the reference point to which the vowels in the emphatic context are compared. The plain context is therefore the base against which changes in the emphatic context are considered. As the emphatic consonants are distinguished from their plain counterparts by their secondary articulation and both classes have a primary articulation, this comparison could best show the change in formant frequency patterns that the secondary articulation could cause.

The overall results show that the effect of emphasis on formant frequencies is manifest in an increase in F1 and F3 and a decrease in F2. This pattern is consistent at both the onset and midpoint of adjacent vowels (see mean values in Table 4.2). According to the mean values for F1 and F2, the effect of emphasis decreases at vowel midpoint compared to vowel onset while F3 is similarly affected at both the onset and midpoint. The general impression indicates that changes in formant frequencies under the influence of emphasis are more considerable for the first two formants than for the third one. The mean and percentage differences between the plain and emphatic contexts are small for F3, but the difference is still statistically significant as explained later in this section, possibly due to the large number of speakers and tokens. The formant frequency that shows emphatic influence the most is F2 followed by F1 and F3 respectively (see the difference between plain and emphatic contexts in Table 4.2).

Table 4.2. Mean formant frequencies in Hertz and % difference

Formant frequencies	plain	Emphatic	Hz difference	% difference
F1 onset	400	446	46	12
F1 midpoint	453	481	28	6
F2 onset	1659	1232	427	26
F2 midpoint	1545	1303	242	16
F3 onset	2610	2660	50	1.91
F3 midpoint	2574	2623	49	1.90

Formant frequency results show that the emphatic context is associated with significantly higher F1 and F3 and lower F2 than the plain context; these results are true for vowel onset and midpoint when all vowels are factored in (see Table 4.3). The patterns for the first three formant frequencies at the onset and midpoint also differ significantly across different vowels. This is expected given that vowels are characterised by different formant frequency patterns.

Table 4.3. Anova results for formant frequencies

dependent variable	independent variables	
	plain/emphatic	vowel quality
F1 onset	$F(1, 2735) = 2750.557, p < 0.001$	$F(7, 2735) = 2245.782, p < 0.001$
F1 midpoint	$F(1, 2735) = 702.101, p < 0.001$	$F(7, 2735) = 3531.538, p < 0.001$
F2 onset	$F(1, 2733) = 17234.326, p < 0.001$	$F(7, 2733) = 2629.372, p < 0.001$
F2 midpoint	$F(1, 2735) = 4702.658, p < 0.001$	$F(7, 2735) = 5187.8, p < 0.001$
F3 onset	$F(1, 2733) = 187.708, p < 0.001$	$F(7, 2733) = 61.539, p < 0.001$
F3 midpoint	$F(1, 2736) = 135.926, p < 0.001$	$F(7, 2736) = 119.375, p < 0.001$

This study is basically concerned with comparing the plain with the emphatic contexts. However as this study includes twenty speakers, three different consonantal types and eight vowels, the effect of the plain and emphatic contexts on formant frequencies can be affected by other independent variables. Results from a two way Anova confirms this (see Table 4.4); there is a significant interaction effect between plain/emphatic and subject in addition to plain/emphatic and vowel quality. There is only a significant interaction effect between plain/emphatic and consonantal type for F1 onset, F2 onset and F2 midpoint. There is no significant interaction effect between plain/emphatic and consonantal type as far as F1 midpoint, F3 onset and F3 midpoint are concerned (see shaded boxes in Table 4.4).

Table 4.4. Results from two way Anova for interaction effects

dependent variable	interaction between independent variables		
	plainemphatic* subject	plainemphatic* consonantal type	plainemphatic* vowel quality
F1 onset	$F(19, 2735) = 10.510, p < 0.001$	$F(2, 2735) = 15.904, p < 0.001$	$F(7, 2735) = 34.786, p < 0.001$
F1 midpoint	$F(19, 2735) = 4.053, p < 0.001$	$F(2, 2735) = 1.263, p > 0.05$	$F(7, 2735) = 13.547, p < 0.001$
F2 onset	$F(19, 2733) = 34.449, p < 0.001$	$F(2, 2733) = 189.585, p < 0.001$	$F(7, 2733) = 16.376, p < 0.001$
F2 midpoint	$F(19, 2735) = 13.051, p < 0.001$	$F(2, 2735) = 15.645, p < 0.001$	$F(7, 2735) = 86.216, p < 0.001$
F3 onset	$F(19, 2733) = 11.451, p < 0.001$	$F(2, 2733) = 1.65, p > 0.05$	$F(7, 2733) = 66.372, p < 0.001$
F3 midpoint	$F(19, 2736) = 5.117, p < 0.001$	$F(2, 2736) = 2.741, p > 0.05$	$F(7, 2736) = 43.792, p < 0.001$

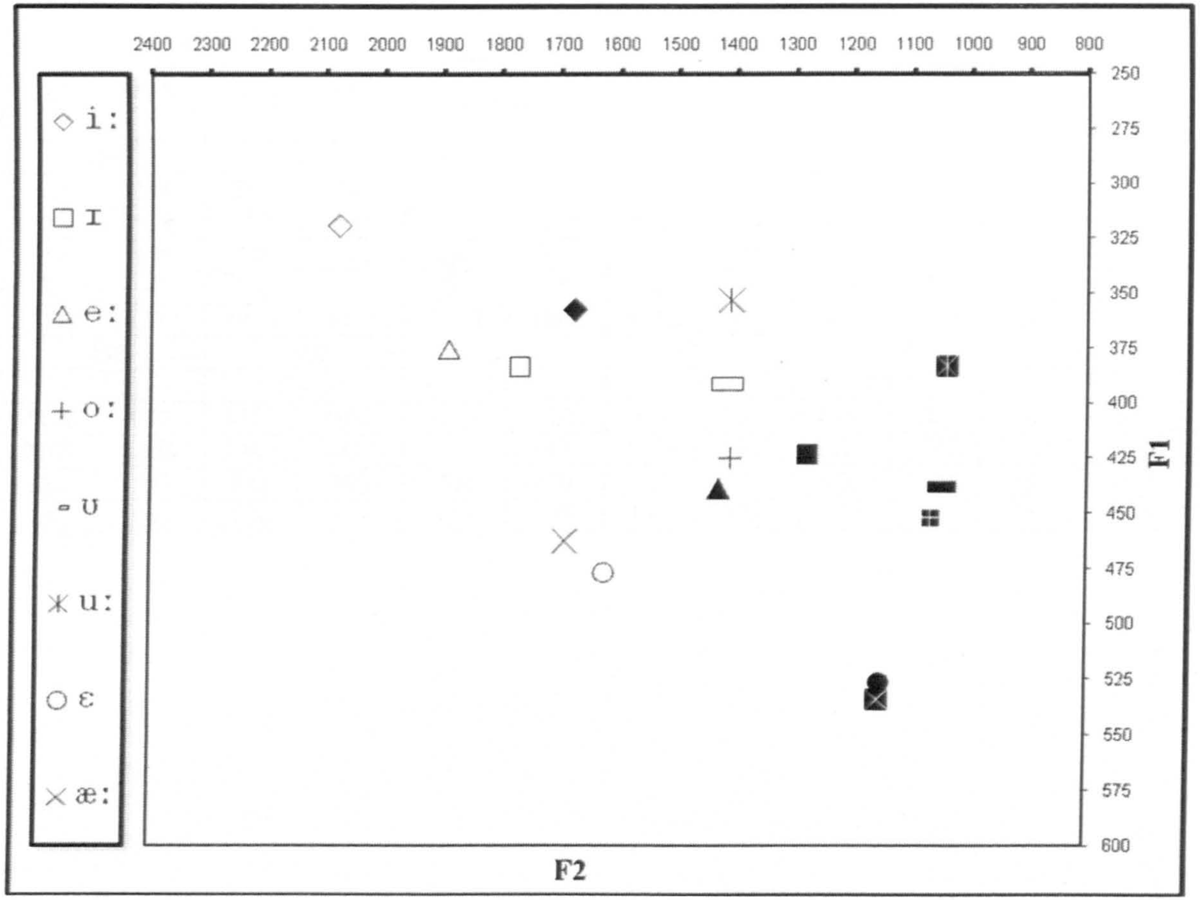
4.3. F1 and F2 patterns

In this section, F1 and F2 results are examined together by plotting F1 against F2. This is first employed by Joes (1948), and has since been used by other researchers, looking at acoustic and articulatory changes in vowel patterns. F1 is generally associated with vowel height and F2 with vowel backing (Kent and Read 1992). By plotting F1/F2 results on a formant frequency chart, using the y axis for F2 and the x axis for F1, one can obtain a graphic representation of the acoustic manifestation of the plain and emphatic consonants that is comparable to an IPA quadrilateral of these vowels, representing their auditory and/or articulatory quality. Datapoints are created for F1 and F2 at the onset first and then at the midpoint for the mean values for each vowel as produced by all speakers. The general formant frequency pattern at the onset and midpoint is discussed in sections 4.3.1 and 4.3.2 before moving to discussing individual vowels in sections 4.3.3, 4.3.4 and 4.3.5.

4.3.1. F1 and F2 onset

The effect of emphasis on formant frequency patterns of the following vowel is best observed on F1 and F2 at vowel onset. According to results from the independent sample t-test, F1 onset is significantly higher in the emphatic than in the plain context whereas F2 onset is significantly lower in the emphatic than in the plain context (see statistical results in appendix 3a). This level of significance for F1 and F2 at vowel onset remains constant for all vocalic contexts. Vowels in the emphatic context therefore have a tendency to move towards a more backed and comparatively lower position than vowels in the plain context (see Figure 4.1). This demonstrates how the emphatic and plain consonants have opposing impacts on the onset of the following vowel. Although significance is found for F1 and F2, the frequency change is more robust for F2 (see the % difference in Table 4.5).

Fig. 4.1. Mean F1/F2 onset datapoints for 8 vowels in plain and emphatic contexts[7]



[7] Empty shapes are used for the plain contexts and corresponding ones filled in black for the emphatic contexts. This applied to figure 4.2.

Table 4.5. Descriptive statistics for F1 and F2 onset in plain (P) and emphatic (E) contexts

Vowel	/iː/		/ɪ/		/eː/		/oː/		/ʊ/		/uː/		/ɛ/		/æː/	
context	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E
F1 onset	319	358	384	423	376	439	425	452	391	438	353	383	477	526	463	534
Hz difference	39		39		63		27		43		30		49		71	
% difference	12.23		10.2		16.8		6.4		11		8.5		10.3		15.3	
min	239	293	311	344	284	348	344	360	305	292	270	315	349	433	370	430
max	399	440	463	519	492	559	548	579	501	573	432	502	592	648	579	654
range	160	147	152	175	208	211	204	219	196	281	162	187	243	215	209	224
SD	26	32	32	40	33	36	36	35	38	39	29	31	46	43	46	44
F2 onset	2080	1677	1771	1280	1891	1431	1412	1068	1448	1073	1411	1054	1626	1153	1693	1156
Hz difference	-403		-492		-460		-344		-375		-357		-473		-537	
% difference	-19.4		-27.8		-24.3		-24.4		-26		-25.3		-29.1		-31.7	
min	1728	1146	1458	957	1595	1025	1071	807	1062	787	901	731	1302	818	1423	844
max	2404	2268	2141	1659	2167	1821	1775	1399	1839	1407	1829	1760	1869	1395	1954	1376
range	676	1122	683	702	572	796	704	592	777	620	928	1029	567	577	531	532
SD	140	209	136	163	126	158	150	119	157	133	194	140	112	111	121	113

4.3.2. F1 and F2 midpoint

Comparison of formant frequencies between plain and emphatic contexts at vowel midpoint was conducted to investigate whether the effect of emphasis extends to vowel midpoint. F1 increase and F2 decrease under the influence of the emphatic consonant is still highly significant, and the level of significance is true for F1 and F2 at the midpoint of all vocalic contexts (see statistical results in appendix 3b) although the formant frequency difference between plain and emphatic consonants is reduced at vowel midpoint if compared to vowel onset (see Table 4.6). The magnitude of the formant frequency difference between the two contexts at the midpoint varies with the vocalic context (see F1/F2 datapoints in Figure 4.2). The effect of the emphatic consonant is not very considerable at vowel midpoint as far as the vowels /iː eː uː oː ʊ/ are concerned. In the emphatic context, the values for formant frequencies for the long vowels /iː eː uː oː/ can approach, to some extent, those of the formant midpoint in the plain context. The extent of emphasis' effect is more pronounced in the case of the short vowel /ɪ/, whose formant frequencies are considerably affected at vowel midpoint. So in the emphatic environment, this short vowel never reaches or approaches the typical formant midpoint value found in the plain context. Thus vowel duration shapes the influence of the emphatic consonant, which extends not only to the onset, but also to the midpoint.

The short front open-mid unrounded /ɛ/and long front near open unrounded /æː/ vowels behave similarly in the sense that their formant frequencies are considerably affected at vowel midpoint despite the fact that one is short and the other is long. This has reflections on the characteristics of the allophonic realisations in the plain and emphatic contexts. Their quality being relatively low seems to interact with the emphatic consonants' articulatory gesture.

Fig. 4.2. Mean F1/F2 midpoint datapoints for 8 vowels in the plain and emphatic contexts

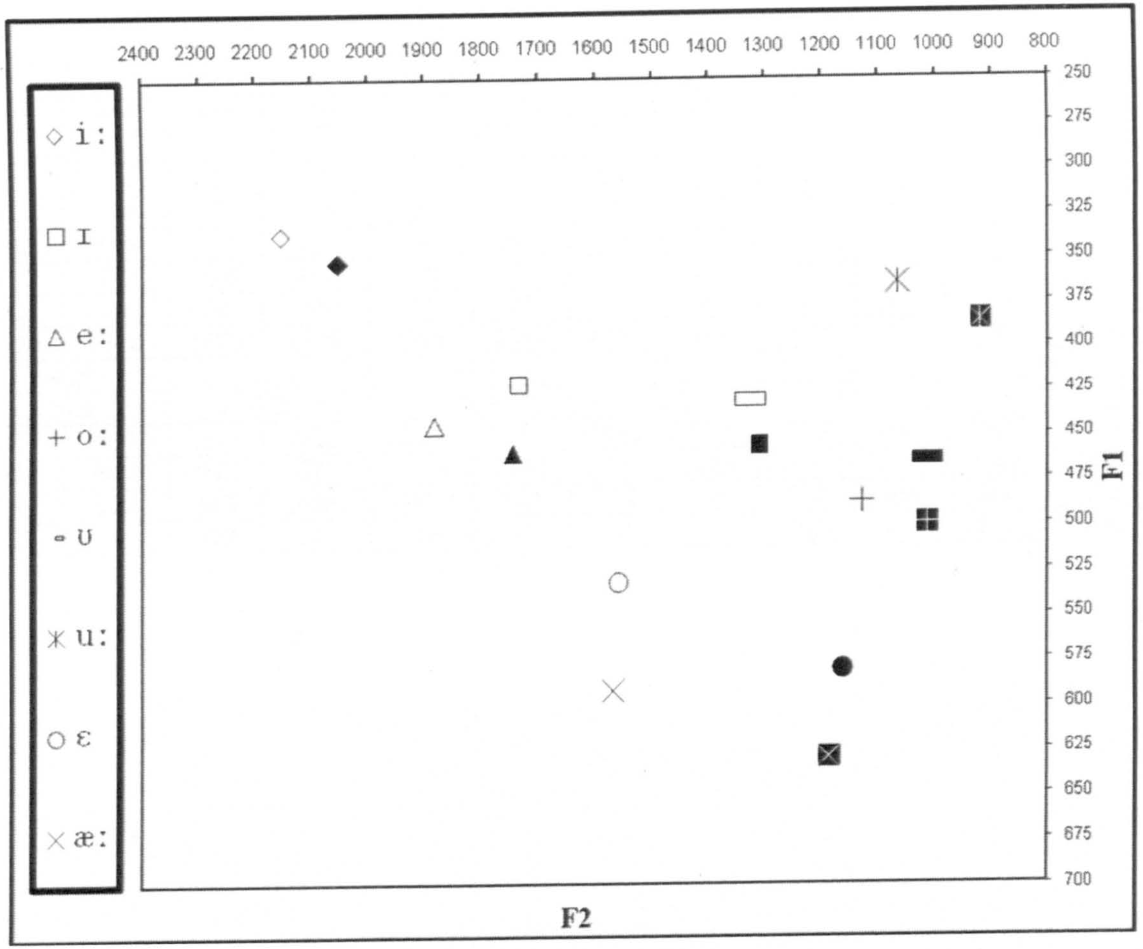


Table 4.6. Descriptive statistics for F1 and F2 midpoint in plain (P) and emphatic (E) contexts

Vowel	/i:/		/ɪ/		/e:/		/o:/		/ʊ/		/u:/		/ɛ/		/æ:/	
context	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E
F1 mid	338	353	423	456	444	460	488	500	431	464	368	392	533	581	593	631
Hz difference	15		33		16		12		35		24		48		38	
% difference	4.43		7.8		3.6		2.5		7.7		6.5		9		6.4	
min	262	276	352	244	327	323	405	410	358	356	294	307	378	493	480	554
max	462	515	532	586	555	535	584	589	530	577	448	460	671	713	726	804
range	200	239	180	342	228	212	179	179	172	221	154	153	293	220	246	250
SD	32	36	33	44	36	35	32	31	38	40	29	31	42	42	41	43
F2 mid	2155	2059	1735	1310	1883	1745	1129	1012	1352	1040	1074	918	1560	1162	1568	1186
Hz difference	-96		-425		-138		-117		-312		-156		-398		-382	
% difference	-4.45		-24.5		-7.3		-10.4		-23.1		-14.5		-25.5		-24.4	
min	1833	1755	1417	933	1616	1425	844	817	1022	715	800	612	1183	909	1320	911
max	2476	2353	2183	1861	2185	2225	1433	1359	1745	1330	1697	1275	1865	1424	1805	1363
range	643	598	766	928	569	800	589	542	723	615	897	663	682	515	485	452
SD	144	141	137	195	122	142	116	91	162	117	162	113	117	100	97	92

The following sections shed some light on different vocalic contexts with data representing all speakers. This also shows how vowels which share similar articulatory features exhibit similar auditory and acoustic manifestation in the context of the emphatic consonants, taking into account the auditory analysis discussed in section 4.1.

4.3.3. Front vowels /iː eː ɪ/

The vowels /iː/ and /eː/ show similar emphasis effect regarding F1 increase and F2 decrease at their onset and midpoint. These vowels share qualitative and quantitative similarities given that both are high and front long vowels. The effect of emphasis on /iː/ and /eː/ is substantial at the onset of these long vowels, but decreases as these long vowels reach their midpoint and thus move towards the F1 and F2 found in the plain context. The distribution of F1/F2 results at onset and midpoint shows a great deal of variation and overlap between plain and emphatic contexts (see Figure 4.3). This overlap is small at the onset, but considerable at midpoint, reflecting the decreasing effect of emphasis as being consistent for almost all speakers when these vowels reach their midpoint.

The high front short vowel /ɪ/ in this study has been shown to be different in quality from the high front long vowel /iː/ as shown by its formant frequencies, particularly F1 and F2 (see Tables 4.5 and 4.6) and the durational difference (see more discussion on the effect of vowel duration on formant undershoot in section 4.8). A recent study on LA has also shown similar qualitative and quantitative differences between these vowels (Ahmed 2008).

Fig. 4.3. F1/F2 onset and midpoint datapoints for /iː/ and /eː/

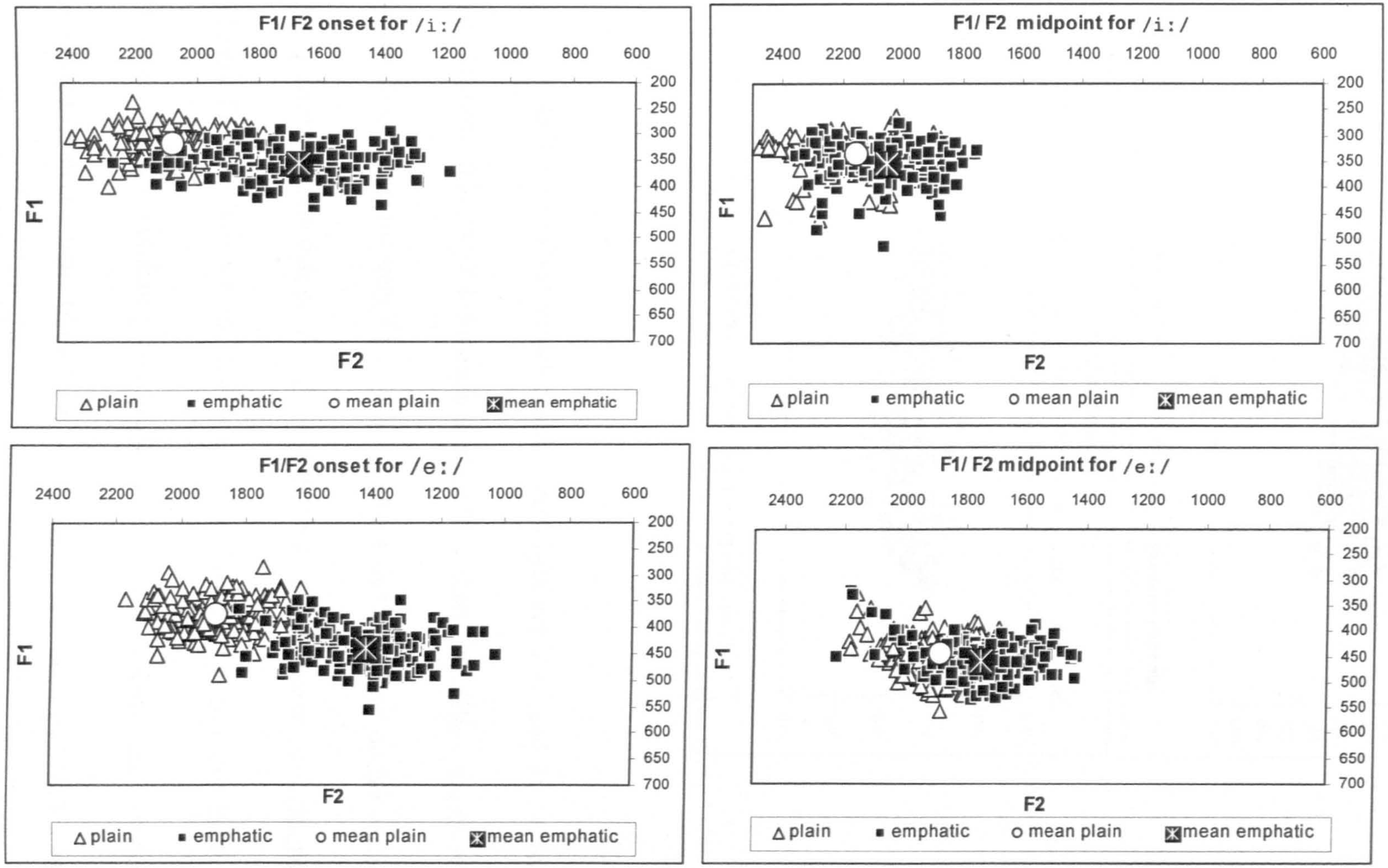
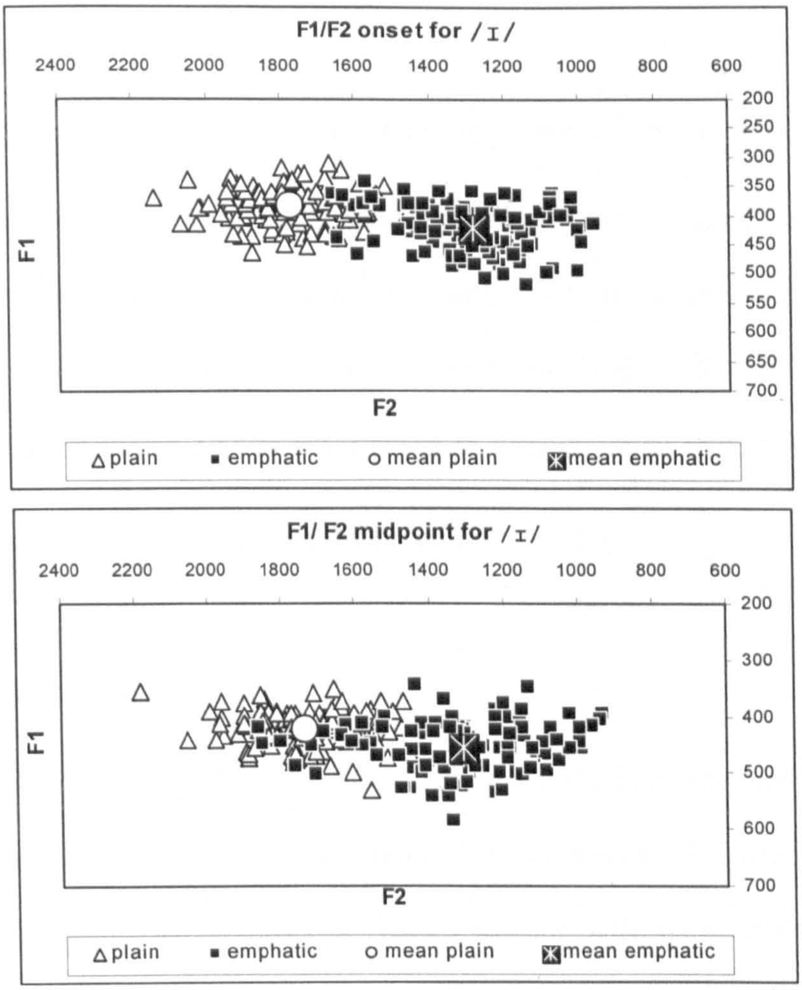


Fig. 4.4. F1/F2 onset and midpoint datapoints for /ɪ/



In addition to these acoustic differences between /ɪ/ and /iː/, auditory analysis shows that /iː/ is higher and more front than /ɪ/. Thus, the short vowel is more central than the long /iː/. The emphatic-induced effect on the short vowel /ɪ/ is different from that on /iː/ since this effect is extensive on both onset and midpoint for the short vowel. The vowel /ɪ/ being short is more likely to be undershot by the emphatic consonant, while /iː/ being long successfully approaches its steady state. In the case of /ɪ/, there is a slight overlap between the plain and emphatic datapoints at both the onset and midpoint (see Figure 4.4).

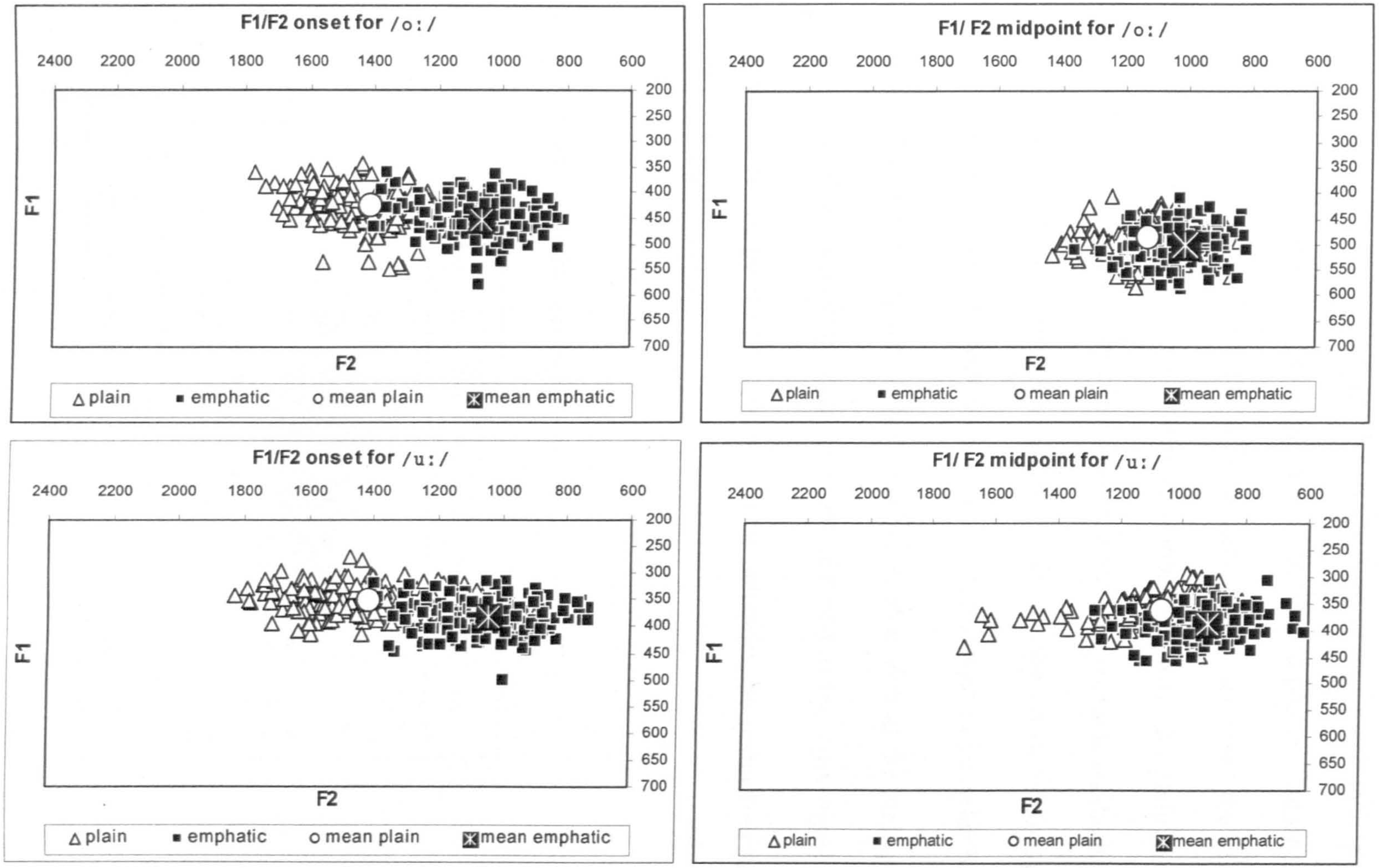
Variation in the realisation of this vowel is prominent in the plain and emphatic contexts.

F1 and F2 for /ɪ/ are closer in the emphatic context than in the plain one due to considerable F2 lowering which is more apparent than F1 raising as shown by the magnitude of the difference between plain and emphatic contexts for each formant frequency at the onset and midpoint (see Tables 4.5 and 4.6). This reveals how the short vowel /ɪ/ is more prone to coarticulation with the backing gesture of the emphatic consonant than the long vowel /iː/.

4.3.4. Back vowels /oː uː ʊ/

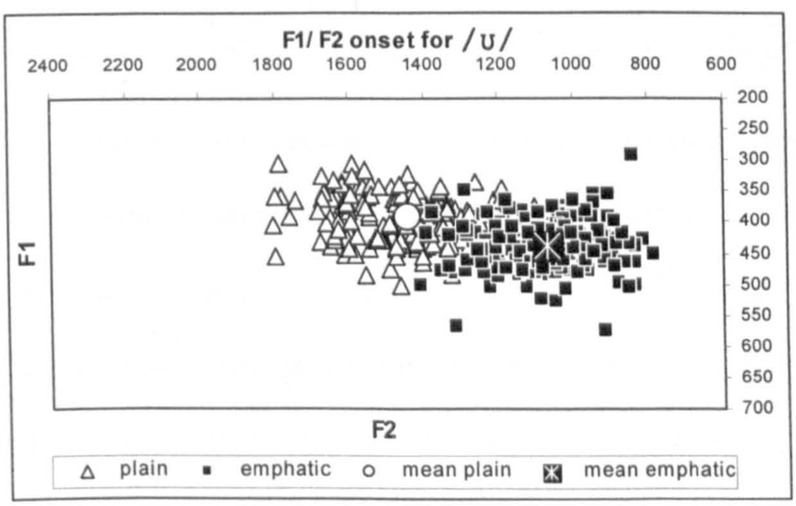
The back vowels are less influenced by the emphatic consonants than the front vowels. However, the substantial formant frequency difference between the plain and emphatic contexts (see Tables 4.5 and 4.6), particularly at the onset of /oː/ and /uː/ and the onset and midpoint of /ʊ/ may be due to the fact that, in the case of these vowels, it is their occurrence in the plain context that is showing influence on their articulation the most, due to the incompatibility between coronal and back articulations; this manifests itself in F1 decrease and F2 increase. F2 onset increases remarkably in the plain context due to the coarticulation resistance the plain context exerts on the conflicting gesture of the back vowels /oː uː/. As for the short /ʊ/, F2 is high at the onset and midpoint, reflecting the extensive formant undershoot on the part of the plain context. This shows an interaction between the plain/emphatic context and vowel quality. The plain-emphatic distinction is enhanced by the opposing articulatory nature of both classes of consonants and the degree to which their articulation differs from the articulation of adjacent segments.

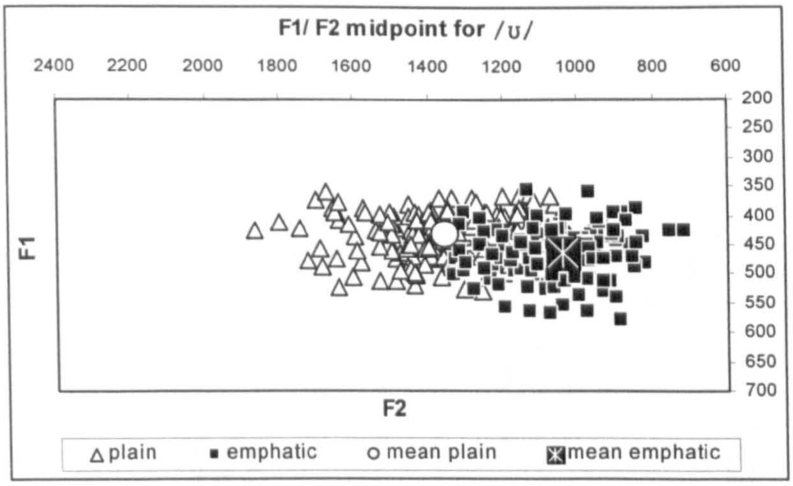
Fig. 4.5. F1/F2 onset and midpoint datapoints for /o:/ and /u:/



Speaker variation is observed at the onset and midpoint of the back vowels /oː uː ʊ/ in both plain and emphatic environments. There is also a small overlap between the plain and emphatic acoustic vowel space at the onset of the long vowels and this overlap becomes greater as the long vowels reach their midpoint (see Figure 4.5). Generally speaking, vowels in the emphatic context can be characterised by being further back in the acoustic space, reflecting the relatively lower F2 for the emphatic environment in comparison with the plain one. The datapoints reveal that there is more overlap between both contexts on the high-low dimension than on the front-back one, reflecting the greater effect of emphasis on F2 as compared to F1. For the short back vowel /ʊ/, the degree of overlap between plain and emphatic vowel space remains small at onset as well as the midpoint (see Figure 4.6), confirming again that the onset and midpoint of the short vowel /ʊ/ is considerably affected by the plain context. This enhances the distinction between plain and emphatic allophones.

Fig. 4.6. F1/F2 onset and midpoint datapoints for /ʊ/

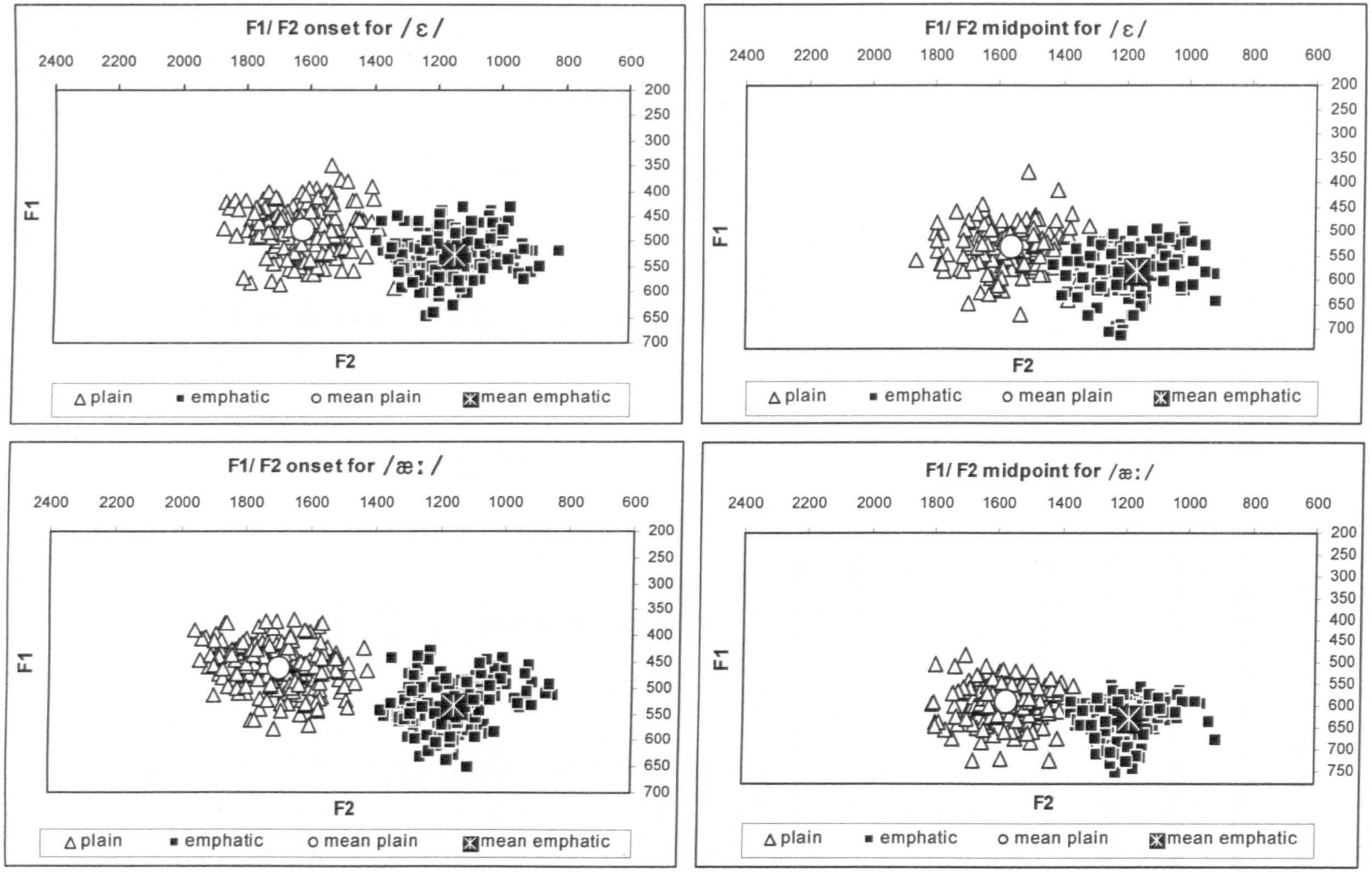




4.3.5. Low vowels /ɛ æː/

At the onset and midpoint of the short front open-mid unrounded /ɛ/ and long front near open unrounded /æː/, there is a great deal of variation in formant frequencies for both plain and emphatic environments. There is very little overlap along the front-back dimension, but some overlap along the high-low dimension with a general tendency for F1 to be higher in the emphatic than in the plain environment (see Figure 4.7). The slight overlap in the acoustic vowel space along the front-back dimension suggests that the plain and emphatic realisations of /ɛ/ and /æː/ are consistently well distinguished by their F2 values for all speakers. Thus low vowels move across the front-back acoustic space to achieve compatibility with the articulation of the emphatic gesture. F2 is influenced more considerably than F1 in the plain-emphatic categorisation (see also Tables 4.5 and 4.6). These acoustic changes are well manifested in the auditory impression of these low vowels in that the plain and emphatic allophones of this vowel are realised completely differently (see auditory analysis in section 4.1).

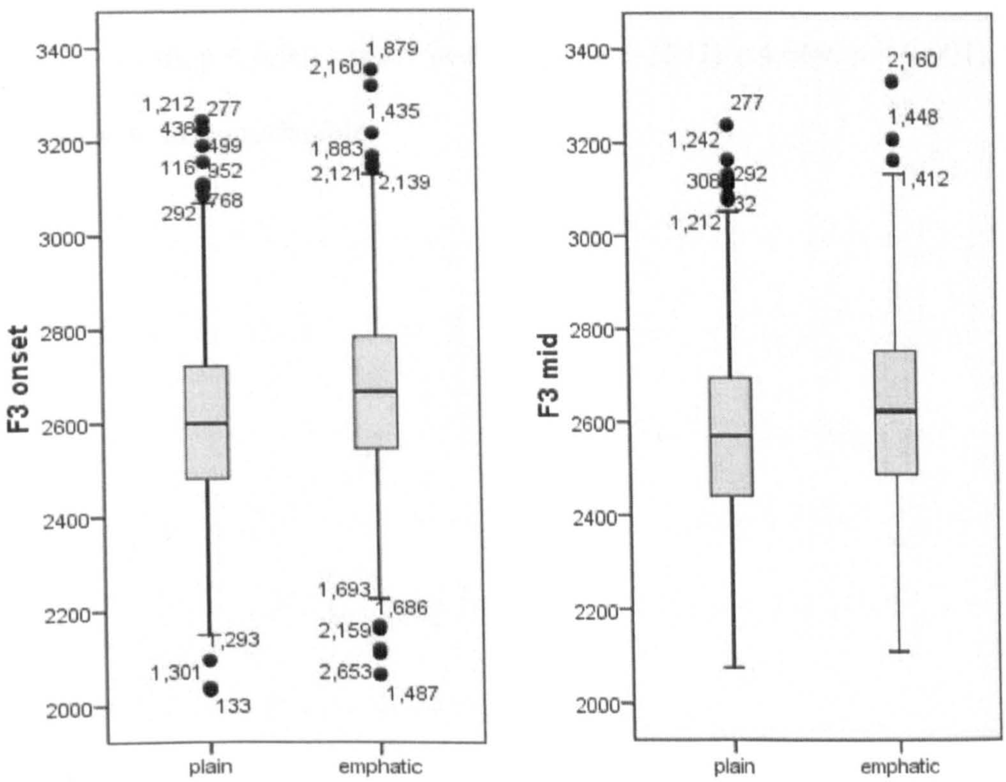
Fig. 4.7. F1/F2 onset and midpoint datapoints for /ɛ/ and /æː/



4.4. F3 results

The overall results representing all vocalic contexts demonstrate that F3 is significantly higher in the emphatic context than in the plain one. According to Anova tests, this significance is consistent for both F3 onset ($F(1, 2734) = 187.708$, $p < 0.001$) and F3 midpoint ($F(1, 2734) = 135.926$, $p < 0.001$) in spite of the small mean differences between the plain and emphatic environment (see discussion in section 4.2). Generally speaking, the overall distribution of data shows that the increasing effect of emphasis on F3 onset is similar to that on F3 midpoint as illustrated by the median, the boxes and the top and bottom whiskers[8] (see Figure 4.8).

Fig. 4.8. The effect of emphasis on F3 at vowel onset and midpoint



[8] The line dividing the box into two parts represents the median, the box 50% of the cases, the top whisker the top 25% of cases and the bottom whisker the bottom 25% of cases. The circles above the top whisker represent the extremely high F3 values and the circles below the whisker represent the extremely low F3 values.

There is a great deal of overlap between the plain and emphatic contexts for both F3 onset and F3 midpoint (see Figure 4.8). There are also some extremely high values for both contexts and for F3 onset and F3 midpoint. Some extremely low values are observed for both plain and emphatic contexts, but only for F3 onset.

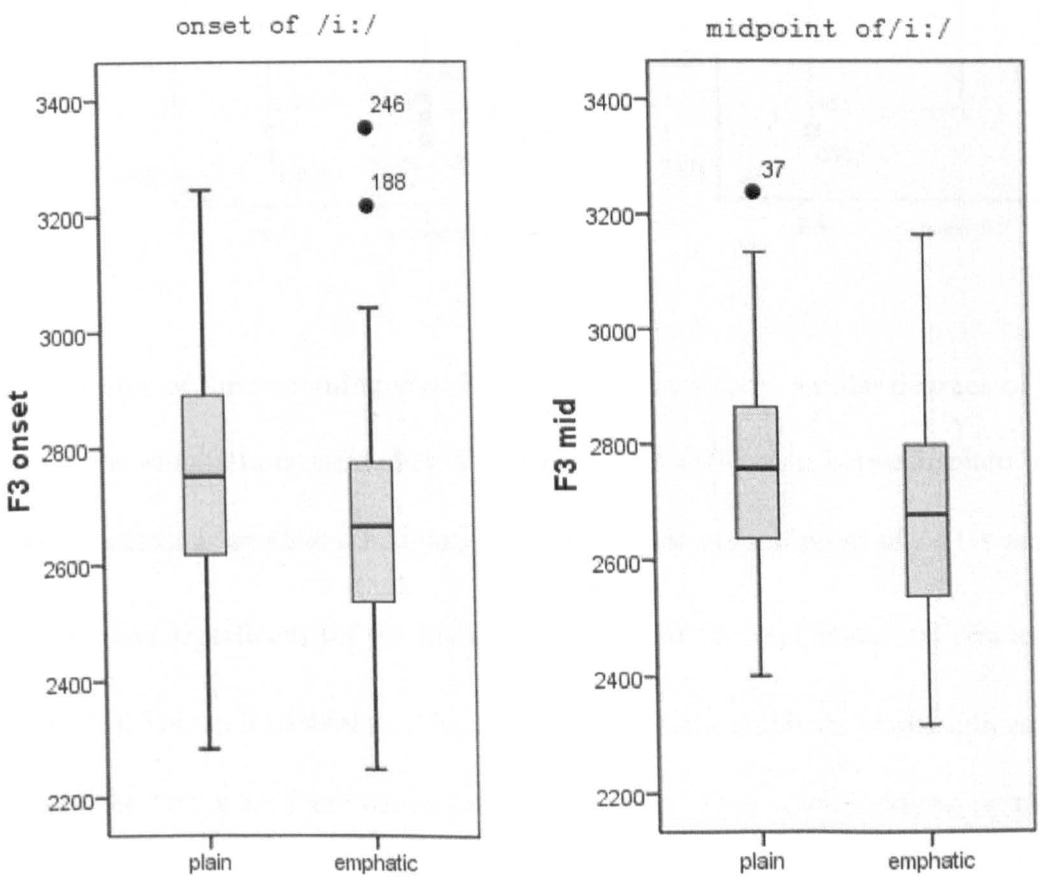
The tendency for the emphatic environment to be associated with F3 increase is observed for all vocalic contexts apart from /iː/, which behaves exceptionally differently (see Table 4.7). The mean values exhibit higher F3 onset and F3 midpoint for /iː/ in the plain context compared to /iː/ in the emphatic context. Moreover, for this vowel, there is more F3 decrease at the midpoint than at the onset, but although, according to the independent sample t-test, the F3 difference between the two contexts is significant for both vowel onset ($t(353) = 5.156$, $p < 0.001$) and vowel midpoint ($t(353) = 4.669$, $p < 0.001$), it does not seem to be considerable.

Table 4.7. Descriptive statistics for F3 in plain (P) and emphatic (E) contexts

Vowel	/iː/		/ɪ/		/eː/		/oː/		/ʊ/		/uː/		/ɛ/		/æː/	
	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E
mean F3 onset	2760	2663	2632	2685	2646	2674	2538	2665	2526	2636	2491	2690	2620	2624	2644	2662
difference	-97		53		28		127		110		199		4		18	
% difference	-3.5		2		1.06		5		4.4		8		0.15		.68	
max	3246	3352	3054	2969	3158	3096	2893	3054	3070	3169	2984	3319	2999	3091	2935	3151
min	2283	2248	2154	2244	2039	2324	2249	2234	2096	2120	2034	2266	2149	2162	2359	2066
range	963	1104	900	725	1119	772	644	820	974	1049	950	1053	850	929	576	1085
SD	184	170	149	148	147	147	132	150	138	182	164	150	154	198	134	199
mean F3 mid	2762	2682	2602	2710	2619	2626	2478	2584	2495	2599	2493	2622	2584	2608	2590	2593
difference	-80		108		7		106		104		129		24		3	
% difference	-2.9		4.1		0.27		4.3		4.2		5.2		0.93		0.12	
max	3239	3165	2889	3036	2972	2945	2905	3049	2908	3096	2906	3333	2943	3209	3165	3111
min	2402	2319	2329	2328	2267	2299	2075	2173	2081	2109	2166	2210	2100	2115	2093	2150
range	837	846	560	708	705	646	830	876	827	987	740	1123	843	1094	1072	961
SD	168	170	128	148	138	142	149	163	145	189	143	159	155	210	184	218

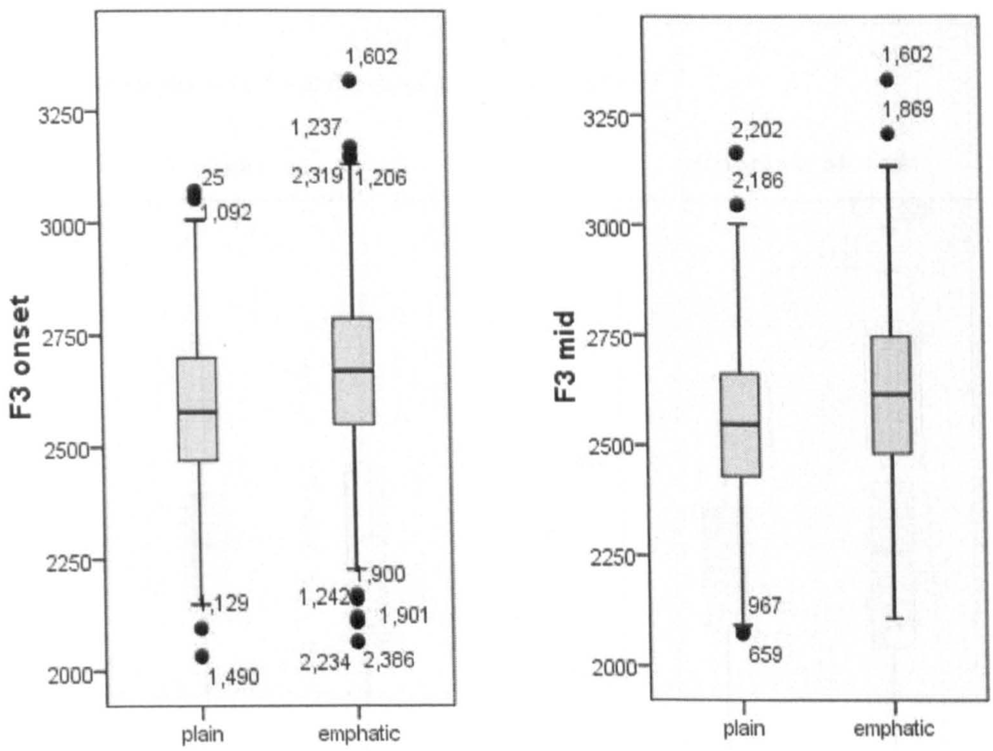
The distribution of data shows that F3 for /i:/ tends to decrease in the emphatic context compared to the plain context (see Figure 4.9). There is an area of considerable overlap between the two contexts, particularly at vowel midpoint. This indicates that F3 decrease in the emphatic context is more evident at vowel onset than at vowel midpoint. Yet the median difference between the plain and emphatic contexts is noticeable at both F3 onset and F3 midpoint. At both points, the 50% of cases and the bottom 25% of cases show also the tendency for F3 to be lower in the emphatic context. At vowel onset the top 25% of cases tend to reflect a decrease in F3 in the emphatic context, but this is not true for F3 midpoint as the top whisker representing the emphatic context shows a tendency for F3 to be higher in the emphatic than in the plain context.

Fig. 4.9. F3 at the onset and midpoint of /i:/



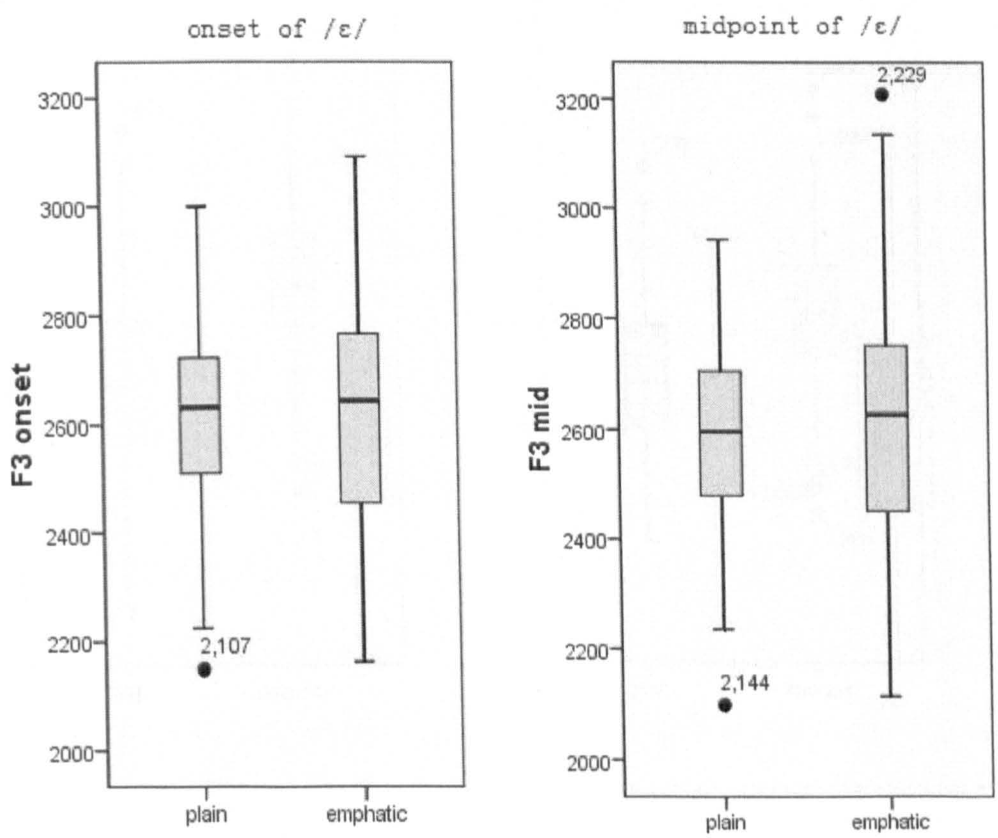
It should be noted that when F3 is replotted to include data for all vocalic contexts but /iː/, the increasing effect of emphasis on F3 at the onset and midpoint becomes more obvious than that when /iː/ is considered (see Figure 4.10). The distribution of F3 is similar for both F3 onset and F3 midpoint.

Fig. 4.10. The effect of emphasis on F3 for all vowels except /iː/



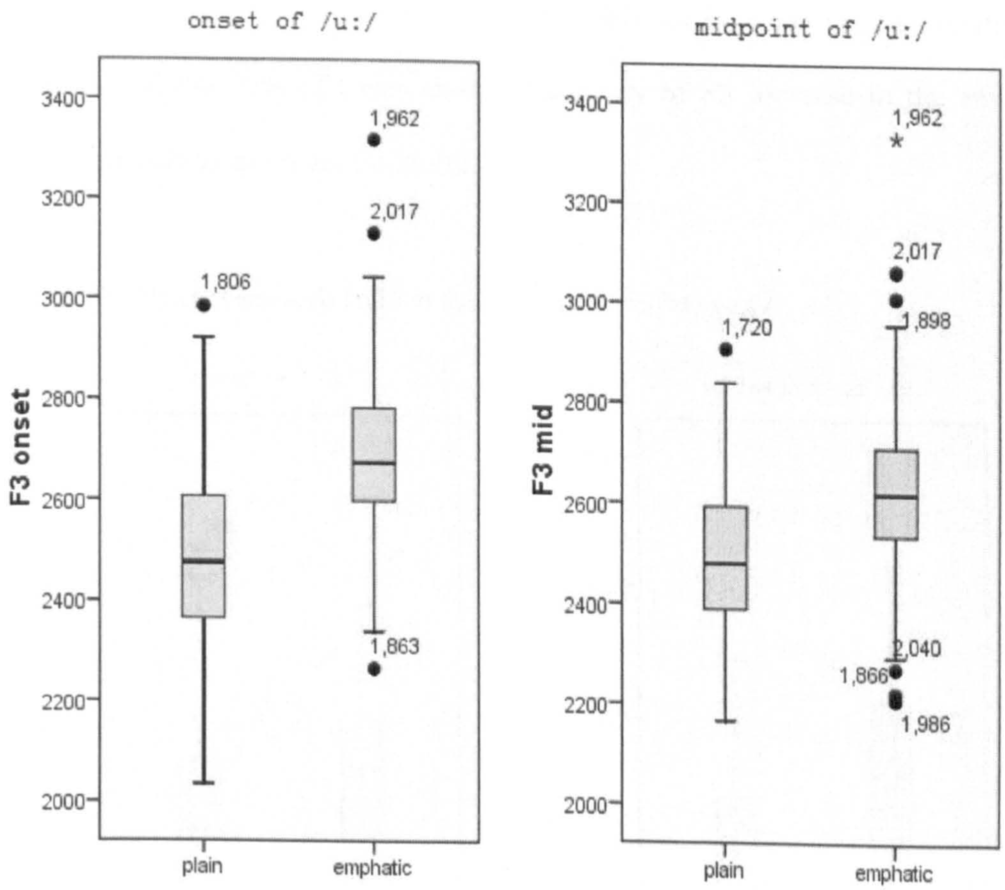
In terms of the remaining vowels, not all contexts show similar degrees of F3 raising in the emphatic context. For instance, the F3 difference between plain and emphatic contexts is small and insignificant at the onset and midpoint of /eː ɛ æː/, and greater and significant for the back vowels /oː ʊ uː/ (see statistical results in appendix 3c). This in turn weakens the F3 role in the plain-emphatic distinction as far as the vowels /eː ɛ æː/ are concerned. Boxplots for these vowels exhibit no clear tendency for the emphatic context to have noticeably higher F3 than the plain context (see Figure 4.11 for /ɛ/ and appendix 1 for /eː/ and /æː/). For instance, for F3 at the onset and midpoint of /ɛ/, there is a great deal of overlap between the plain and emphatic contexts with the lowest and highest values being observed for the emphatic context. Thus the range for F3 is wider for the emphatic than for the plain context.

Fig. 4.11 The effect of emphasis on F3 at the onset and midpoint of /ɛ/



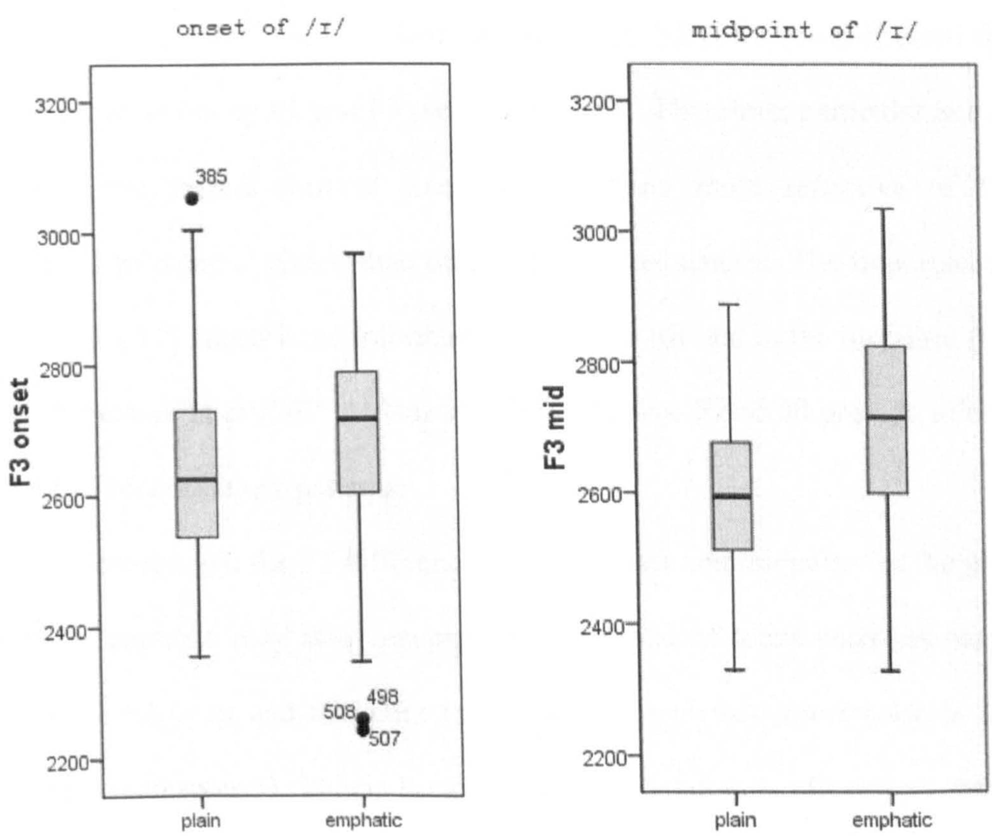
The back vowels therefore provide the best context for the acoustic role of F3 in the plain-emphatic distinction, particularly /uː/ (see Figure 4.12 for /uː/ and appendix 1 for F3 onset and midpoint for back vowels /oː/ and /ʊ/). The degree of overlap between the plain and emphatic contexts diminishes for the back vowels as the increasing effect of emphasis is considerable. This increasing effect is illustrated by the median and boxes and top and bottom whiskers especially for F3 onset (see Figure 4.12).

Fig. 4.12. The effect of emphasis on F3 at the onset and midpoint of /u:/.



The high front short vowel /ɪ/ does not behave acoustically like /i:/ given that the former is associated with an increase in F3 in the emphatic context. The short /ɪ/ yields similar results to those of the back vowels. It should be noted that the F3 difference between the plain and emphatic contexts for /ɪ/ is greater at vowel midpoint than at vowel onset (see also Table 4.5.above and Figure 4.13). The difference is also more significant at vowel midpoint according to the independent sample t-test ($t\ (233) = -6.051$, $p < 0.001$) than at vowel onset as revealed by results from the Mann-Whitney test, the non-parametric version of the independent sample t-test ($z = -3.142$, $p < 0.05$). There is overlap between the two contexts as illustrated by the top 25% of cases and the bottom 25% of cases and the overall distribution of F3 (see Figure 4.13). However, the median difference between the two contexts is noticeable and the 50% of cases show a tendency of F3 increase in the emphatic context particularly at vowel midpoint.

Fig. 4.13. The effect of emphasis on F3 at the onset and midpoint of /ɪ/



Although F3 could provide some acoustic information about the plain-emphatic distinction in some vocalic contexts, its role is not as robust as the role played by the two lower formant frequencies, particularly F2, due to lack of consistency of the F3 results across different vocalic contexts. The general results and results for most vocalic contexts, which have shown a consistent pattern for F3 increase in the emphatic context, seem to suggest that emphasis affects F3.

4.5. Coarticulatory significance of formant frequencies

This section makes use of the formant frequency analysis conducted for the onset and midpoint of vowels following plain and emphatic consonants in order to examine the formant frequency movements from onset to midpoint and their implications for coarticulation. Generally speaking, F2 is the most affected formant frequency followed by F1 and F3 (see Figure 4.14). Therefore, particular attention is given to the second formant frequency as being more reflective of formant transitions between C and V than other formant frequencies. The importance of F2 in providing CV transitional information is also confirmed in the literature (Delattre 1951; Liberman et al 1967; Al-Nuzaili 1993) and thus F2 could provide information about CV coarticulatory patterns.

Accordingly, the F2 difference between onset and midpoint for the plain and emphatic contexts may also account for the results of locus equation parameters which use F2 onset and midpoint to encode coarticulatory information in the next chapter (see chapter 5). This is because CV coarticulation is affected by the quality of adjacent vowels. The F2 change from onset to midpoint is described for different vowels to reveal how the effect of plain/emphatic context changes as the vowel approximates its midpoint.

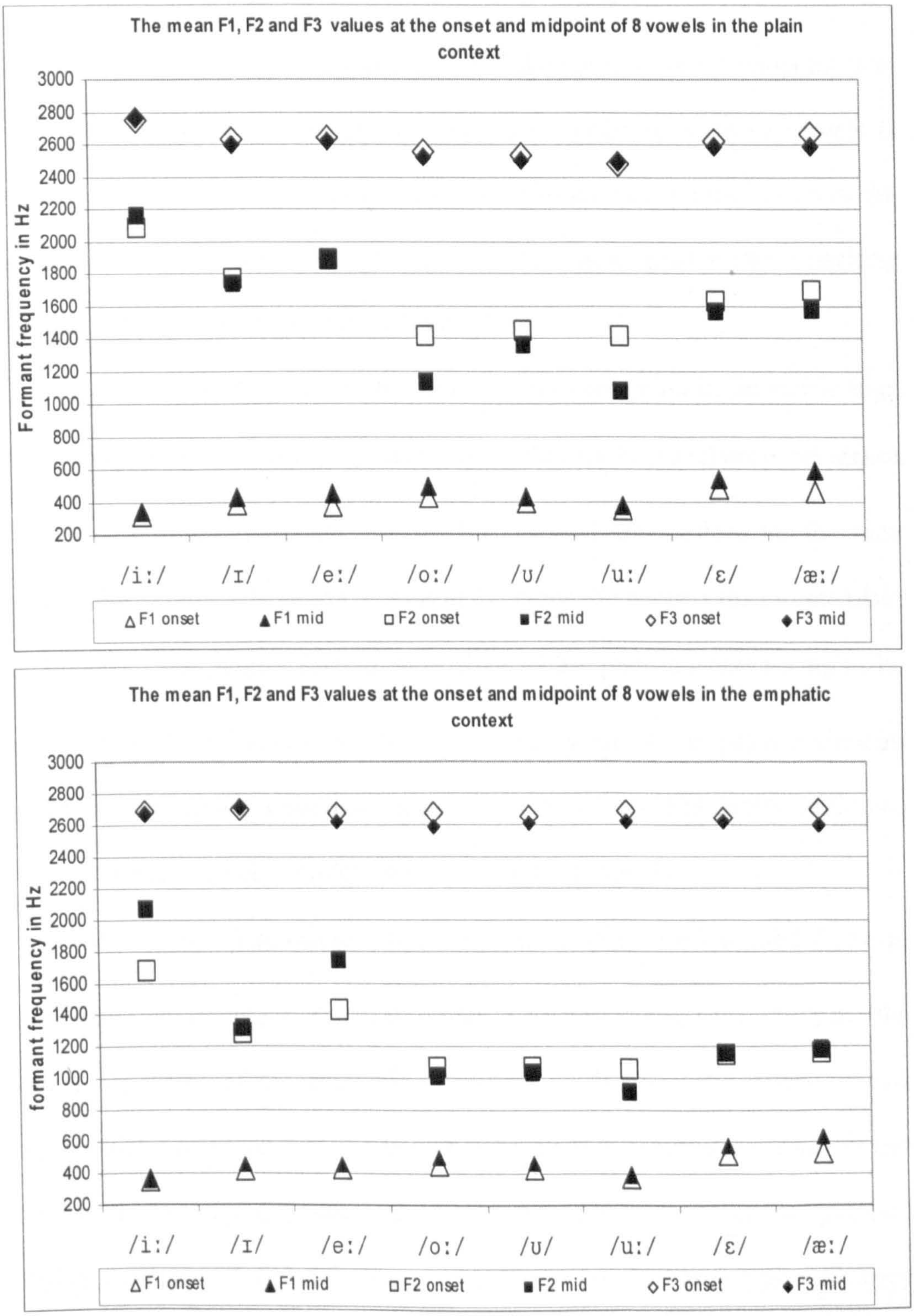
Table 4.8. Descriptive statistics for F2 onset and F2 midpoint

V	plain environment				emphatic environment			
	F2 onset	F2 mid	Hz difference	% difference	F2 onset	F2 mid	Hz difference	% difference
/i:/	2080	2155	75	3.5	1677	2059	382	19
/ɪ/	1771	1735	36	2.1	1280	1310	30	2.3
/e:/	1891	1883	8	0.42	1431	1745	314	18
/o:/	1412	1129	283	25	1068	1012	56	5.5
/ʊ/	1448	1352	96	7	1073	1040	33	3.2
/u:/	1411	1074	337	31	1054	918	136	15
/ɛ/	1626	1560	66	4	1153	1162	9	0.8
/æ:/	1693	1568	125	8	1156	1186	30	2.5

For the high front long vowels /i:/ and /e:/, the considerable lowering effect of emphasis on F2 onset shapes the transition between the emphatic and the vowel which has higher F2 midpoint. Such an effect diminishes gradually as the vowel reaches its midpoint, creating a large F2 onset-F2 midpoint difference (see Table 4.8). Accordingly, high and front long vowel articulations resist the emphatic gesture. On the other hand, in the plain context, a small F2 percentage difference of 3.5 between onset and midpoint is negligible due to compatibility between the articulation of coronal plain consonants and that of high front long vowels.

The close F2 onset (1279 Hz) and F2 midpoint (1310 Hz) values for /ɪ/ in the emphatic environment are suggestive of the role played by vowel length in determining the extent of emphatic coarticulation. The vowel /ɪ/ does not resist coarticulation with the emphatic consonant because it is short and lax. This renders it subject to greater formant undershoot than the long high front vowels whose long duration enable them to approach the F2 midpoint found in the plain context. Likewise, the vowel /ɪ/ coarticulates with the coronal plain consonant because of its nature as a high front vowel rather than its short duration. The F2 percentage difference between onset and midpoint is small at 2.1% in the plain environment.

Fig. 4.14. Formant movement from onset to midpoint



The F2 onset-midpoint difference is small in the emphatic environment for the back vowels /ʊ/ and /oː/ and it becomes bigger for /uː/. As back articulations, these vowels are expected to be compatible with the emphatic-induced backing gesture that causes F2 lowering. These results suggest this compatibility considering the similar F2 onset and midpoint for /ʊ oː uː/ in the emphatic context. These back vowels even display a lower F2 midpoint than F2 onset (see Table 4.8). This shows how the articulation of these vowels is compatible with the back gesture of emphasis. The secondary articulation of the emphatic consonant involves tongue backing, so that emphasis exerts backing effect that is parallel to that of the back vowels.

In the case of the plain context, the F2 onset-midpoint difference is high for the long back vowels /oː/ and /uː/ due to coarticulatory resistance between the coronal consonant and the back vowel articulation. So for back vowels, there is more CV coarticulation in the emphatic context than in the plain one. However, the picture for the short /ʊ/ in the plain context seems to be shaped by its short duration as the F2 raising effect of the plain consonant extends to the midpoint, once again minimising the F2 onset-midpoint difference for the short back vowel in comparison with the long vowels.

As for the F2 movement from onset to midpoint for /ɛ/ and /æː/ in the emphatic environment, this was found to be negligible, accounting for the considerable effect of the emphatic consonant on the acoustic nature of low vowels, which maximises CV coarticulation between the emphatic consonant and these vowels. In the plain context, the F2 difference between onset and midpoint is higher than that observed in the emphatic context. F2 has a high frequency value at the onset, but decreases at the midpoint by 4% for /ɛ/ and 8% for /æ:/. This F2 increase at their onset seems to be triggered by the adjacent coronal plain consonants.

4.6. Speaker variability

The graphic representation and the descriptive statistics observed in the analysis of formant frequencies discussed earlier in this chapter show variability in formant frequency patterns for the plain and emphatic contexts. ANOVA results confirm the presence of highly significant differences between subjects (see Table 4.9) when each of F1, F2 or F3 at the onset and midpoint is regarded as the dependent variable and the subject is the independent variable.

Table 4.9. Anova results for speaker variability

dependent variable	independent variable (speaker)
F1 onset	$F(19, 2735) = 65.268$, $p < 0.001$
F1 mid	$F(19, 2735) = 51.923$, $p < 0.001$
F2 onset	$F(19, 2733) = 153.524$, $p < 0.001$
F2 mid	$F(19, 2735) = 94.265$, $p < 0.001$
F3 onset	$F(19, 2733) = 110.470$, $p < 0.001$
F3 mid	$F(19, 2736) = 125.988$, $p < 0.001$

The auditory analysis yields more consistent results than the acoustic analysis with respect to inter-speaker variation. In all vocalic contexts investigated inter-speaker variation within the same vowel quality are reported in the formant frequency patterns of the vowels in the plain and emphatic contexts. However, the auditory analysis of the vowel quality in the plain and emphatic contexts shows that variation is not always manifest in the plain and emphatic allophones. This might be attributed to various factors. For instance, the acoustic analysis may be more precise and sensitive to any slight changes in the vowel quality which can not be auditorily perceived. Furthermore, as the auditory analysis conducted for this study involves a broad rather than fine-grained narrow phonetic transcription, this may not reflect the differences in formant frequency patterns across speakers. As discussed in the following section, variability can also be induced by the consonantal context.

4.7. The effect of the consonantal context

Results from this study show that the consonantal type could affect formant frequency patterns and lead to variability. This is because a certain consonant could affect formant frequency patterns in a different way as compared to another consonant. The plain-emphatic comparison conducted in this study concerns three plain and three emphatic coronal consonants. In fact, a one way Anova conducted for different consonantal contexts shows that formant frequencies could differ significantly as a function of the consonantal type apart from F2 midpoint (see Table 4.10).

Table 4.10. Anova results for differences between different consonantal types

dependent variable	independent variable (consonantal type)
F1 onset	$F(2, 2735) = 657.929, p< 0.001$
F1 midpoint	$F(2, 2735) = 132.068, p< 0.001$
F2 onset	$F(2, 2733) = 65.139, p< 0.001$
F2 midpoint	$F(2, 2735) =.307, p > 0.05$
F3 onset	$F(2, 2733) = 5.988, p< 0.05$
F3 midpoint	$F(2, 2736) = 6.329, p < 0.05$

The comparison between different consonantal contexts described in this and the following paragraph is based on Bonferroni post hoc tests which are conducted in order to find out where the differences lie (see appendix 3D). Formant frequencies could differ significantly as a function of the consonantal type, and this true for both plain and emphatic contexts (see shaded boxes in appendix 3D for the significant differences). This effect is evident for F1 onset, F1 midpoint and F2 onset.

F1 onset in the context of the voiced /d/ is significantly lower than F1 onset in the context of the voiceless /s/ and /t/ (see also Table 4.11 for mean values). F1 onset in the contexts of /dˤ/ is significantly lower than F1 onset in the context of /sˤ/ and /tˤ/. Similarly, results for F1 midpoint also shows that the voiced plain and emphatic consonants are distinguished from the voiceless plain and emphatic consonants, but generally speaking the statistical difference becomes less significant for F1 midpoint compared to F1 onset. As for F2 onset in the plain context, all the consonantal types are statistically significant from one another. It is noticed that the context of the voiced /d/ has the highest F2 onset (see Table 4.11). The fact that the voiced /d/ is associated with the lowest F1 onset and the highest F2 onset shows an effect of voicing on formant frequency patterns. In the emphatic context, F2 onset in the context of /sˤ/ is statistically higher than that in the context of /tˤ/. The context of /sˤ/ is associated with the highest F2 onset (see Table 4.11). F3 does not show any significant difference between different consonantal types apart from the difference between /dˤ/ and /sˤ/, which is only significant at both the onset and midpoint. There is no statistical difference between different consonantal types as far as F2 midpoint is concerned.

Table 4.11. Mean formant frequencies for different consonantal contexts

formant frequencies	/t/	/s/	/d/	/tˤ/	/sˤ/	/dˤ/
F1 onset	413	412	376	461	452	424
F1 midpoint	462	457	441	488	486	469
F2 onset	1659	1611	1702	1200	1270	1230
F2 midpoint	1548	1528	1558	1316	1311	1283
F3 onset	2606	2598	2611	2660	2646	2675
F3 midpoint	2579	2564	2583	2616	2604	2644

The mean formant frequencies for each consonantal type in different vocalic contexts are provided in appendix 2. F2 at the onset of the back vowels /u u: o:/ in the plain context of /d/ is very high compared to the context of /t/ and /s/. This leads to the early start of vowel formants in the context of a voiced consonant, subjecting the formants to great effect on the part of the preceding voiced consonant as explained above.

It is also observed that F2 at the onset of /i:/ in the emphatic context can approach values found at the onset of the plain context. Most examples in Table 4.12 contain /i:/ in the consonantal environment of /sˤ/ and they are produced with high F2 onset, yet F2 onset for /i:/ in the plain context is still higher than that in the emphatic one, confirming the presence of an F2 difference, a main factor in the plain-emphatic distinction. These values are substantially higher than the mean F2 onset for /i:/ in the emphatic context at 1677 Hz.

Table 4.12. High F2 at the onset of /iː/ in the emphatic context for some tokens[9]

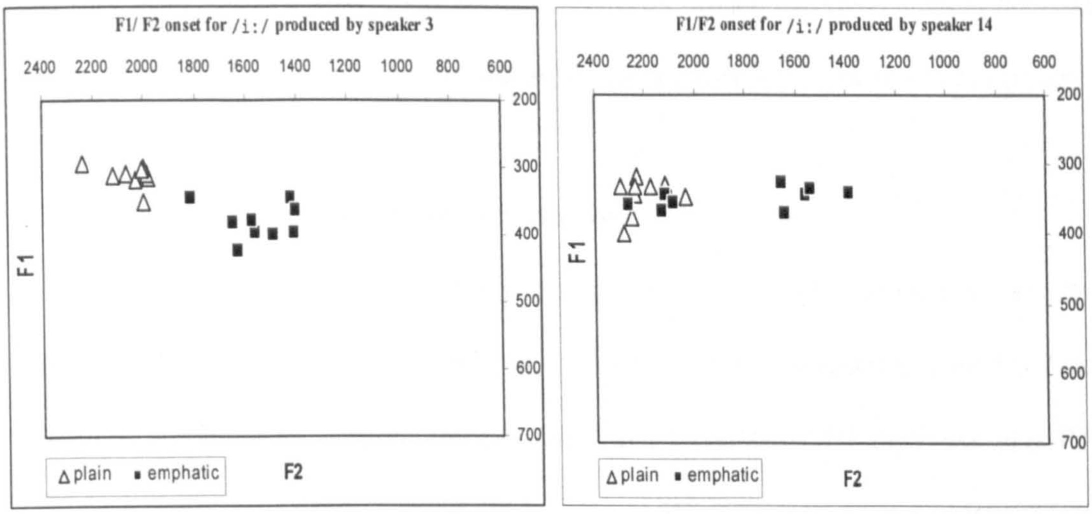
speaker	token	context	plain context	emphatic context	auditory
5	3	/s/-/sˤ/	2032	2010	E
6	1	/s/-/sˤ/	2239	2052	E
6	2	/s/-/sˤ/	2226	2034	E
6	3	/s/-/sˤ/	2334	2152	E
9	1	/s/-/sˤ/	2186	2118	E
10	1	/d/-/dˤ/	2186	2090	E
12	3	/s/-/sˤ/	2120	2049	E
13	1	/s/-/sˤ/	2217	2062	E
13	2	/s/-/sˤ/	2253	2098	E
13	3	/s/-/sˤ/	2334	2132	E
14	1	/s/-/sˤ/	2236	2123	E
14	2	/t/-/tˤ/	2288	2131	E
14	2	/s/-/sˤ/	2299	2268	E
14	3	/s/-/sˤ/	2241	2090	E

Examples of two speakers are provided to show how F2 decrease is not consistent across speakers. For instance, for speaker 3, vowels in the plain context are distinct from vowels in the emphatic context while for speaker 14, they overlap, indicating the presence of not only inter-, but also intra-speaker variation (see Figure 4.15). Therefore, overlap is caused between plain and emphatic datapoints as some of speaker 14's emphatic datapoints overlap with the plain ones. Speaker 14 produces all his three tokens of /sˤ/ with high F2 (see Figure 4.14). This is manifested in the datapoints for these three tokens as they are fronted in the emphatic context and pattern with those in the plain one. The emphatic tokens of interest appear in the figure as the squares in the plain context area marked by the triangles. This shows occasional variations within the same speaker who can produce an emphatic consonant with an F2 onset value that is

[9] F2 onset for the plain context is also provided for comparison

similar to that of the plain consonant yet the emphatic consonant is still auditorily perceived.

Fig. 4.15 The production of plain and emphatics by speakers 3 and 14



Generally speaking, the auditory impression of the vowel /iː/ in the emphatic context sounds similar for both speakers; for both speakers /iː/ is coloured with emphasis. In the case of speaker 14, three overlapped datapoints are from the emphatic context of /sˤ/ and one from that of /tˤ/ (see F2 onset values in Table 4.12). The one in the /tˤ/ context seems to be produced with a lesser degree of emphasis than the others. This may lead to different degrees of backing of adjacent vowels for different tokens. This shows speaker control over the production of emphasis and this control differs from one token to another. As for the other examples in the /sˤ/ context for speakers 14, it is noticed that most examples with high F2 onset come from the context of /sˤ/ (see Table 4.12). It is also reported that the mean F2 at the onset of /iː/ is higher in the /sˤ/

context (1821 Hz) than in the /dˤ/ context (1601 Hz) and the /tˤ/ (1620 Hz). This shows that emphasis may be more pronounced for /sˤ/ than for other emphatics. Although these results seem to suggest potential discrepancy between auditory impression and acoustic results, this may not be the case. This is because the auditory analysis conducted in this study is categorical rather than continuous.

4.8. Summary of formant frequency results

It can be concluded that the presence of the emphatic consonants exerts an effect on the three first formant frequencies of the following vowels. The effect of emphasis is acoustically manifest in F1 increase, F2 decrease and F3 increase. These results are consistent for all vocalic contexts apart from the high front vowel /iː/, in which F3 is higher for the plain than for the emphatic context. The role of the emphatic context in F3 increase is more pronounced in the context of back vowels than other vocalic contexts. Formant frequencies at the midpoint of the plain and emphatic context exhibit a more significant role for F2 than that for F1 and F3 in the plain-emphatic distinction. Although the plain context seems to have lower F1 midpoint than the emphatic one, the difference does not seem to be considerable. The role of F2 midpoint varies depending on the vocalic context. The F2 difference for the vowels /ɪ ʊ ɛ æː/ suggests that the effect of emphasis extends considerably to the midpoint of these vowels. This is because the first three vowels are short and the last vowel changes completely into a back vowel. F2 difference between the plain and emphatic contexts becomes smaller at the midpoint of the long vowels /iː eː oː uː/. F3 patterns at the midpoint are similar to those observed at the onset.

The effect of emphasis on the formant frequencies of the following vowels suggests the presence of a coarticulatory effect. In the next chapter, a further investigation of the coarticulatory effect of emphasis is carried out using locus equation parameters which is based on the regression analysis of F2 onset and F2 midpoint. This chapter has shown that F2 is the most affected formant frequency as far as the effect of emphasis is concerned. F2 holds most CV transitional information.

Chapter Five

Locus Equation Results

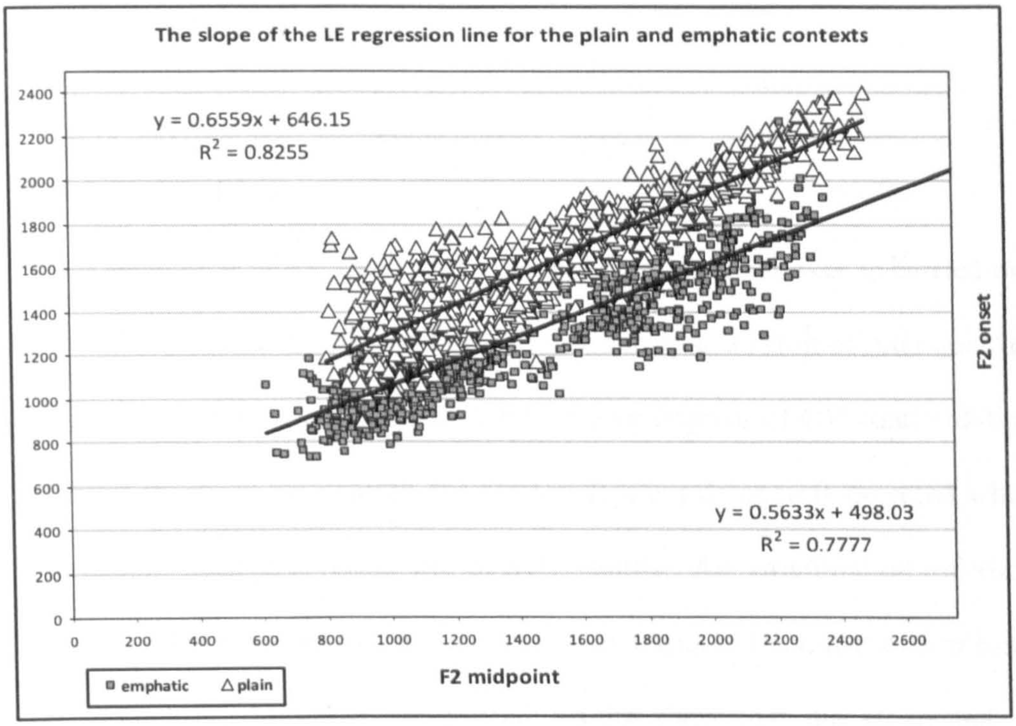
5.0. Introduction

In this chapter, locus equation parameters are employed to investigate any place of articulation difference between the plain and emphatic consonants, taking into account that the LE slope encodes details concerning CV coarticulation and the LE y-intercept could also provide information about the articulation of the emphatic consonants. Locus equations are investigated for data from all speakers and consonantal types to obtain general results in addition to data for each speaker and each consonantal type.

5.1. General results

Datapoints are initially formed for all the data in order to obtain a comprehensive account of the LE parameters regardless of the speaker or the consonantal type. The slope and y-intercept values are lower for the emphatic consonant than for the plain one as can be seen in Figure 5.1. From the slope of the LE line, it is possible to estimate the degree of consonant-vowel coarticulation. The regression lines fitted to the datapoints indicate that the line for the emphatic context is flatter than that for the plain context. This suggests more CV coarticulation for the plain context than for the emphatic context since the flat slopes are strong indications of maximal coarticulatory resistance of the consonant articulation to vowel effects (Krull 1989). Therefore, the emphatic consonants show more resistance to coarticulation with the following vowel than their plain counterparts.

Fig. 5.1. The slope of the regression line for the plain and emphatic consonants



Although the datapoints for both types of consonants occasionally overlap, the majority of datapoints are well-clustered around their regression lines, signalling that LE parameters still characterise the plain consonant as being different from the emphatic one. An independent sample t-test shows that the slope value is significantly lower for the emphatic context than the plain one ($t(118) = 2.850, p<0.05$). The same test shows that the y-intercept value is highly significantly lower for the emphatic context compared to the plain one ($t(118) = 4.466, p<0.001$). This reflects the lower F2 onset for the emphatic context than for the plain context; the low F2 at the onset of all vowels in the emphatic environment as compared to vowels in the plain environment is also reported in the formant frequency results (see chapter 4).

It is clear from Figure 5.1 that variation exists for both contexts. In the following sections, LE parameters are examined for each speaker and each consonantal type.

5.2. Speaker variability

Calculation of LE slope and y-intercept for each speaker is carried out in order to find out how the slope of the LE line varies as a result of inter-speaker variation. This may give an idea about the varying degrees of CV coarticulation for different speakers, accounting for the overlapping datapoints detected when LE regression lines are based on overall results. An examination of each individual speaker provides inconsistent results in terms of the effect of emphasis on LE parameters. Although the overall results show that the slope and y-intercept are lower for the emphatic than for the plain environment, this is not always the case as indicated by the shaded boxes in which the slope and y-intercept can be higher in the emphatic than in the plain environment for some speakers (see Table 5.1).

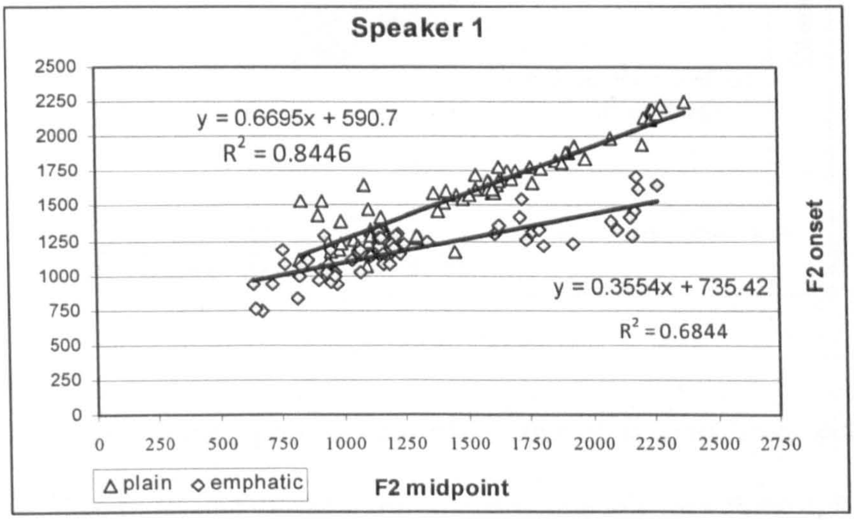
Results from the majority of speakers show that the LE slope values are lower for the emphatic than for the plain context, but with various degrees of lowering. For instance, in the data for speakers 1, 5, 7 and 16 (see appendix 5), the slope values for the emphatic context are considerably lower than those for the plain one with the highest degree of slope lowering being reported at (0.355) for speaker 1, whose slope value for the plain context is (0.67). This considerable difference is manifest in the slope of the LE regression line being flatter for the emphatic than for the plain context, indicating the presence of emphatic-vowel coarticulation resistance as illustrated in Figure 5.2. For this speaker, the F2 onset-F2 midpoint difference in the emphatic context seems to be greater as compared to other speakers. The plain context is characterised by tighter clustering of points around the regression line than the emphatic one; the good fit for the plain context is expressed by the high R^2 value (see Table 5.1). It is also noticed that there is little overlap between the datapoints of both plain and emphatic contexts.

Table 5.1. Slope, y intercept and R^2 for each speaker along with the overall mean and SD

speaker	slope		y-intercept		R^2	
	plain	emphatic	plain	emphatic	plain	emphatic
1	0.67	0.355	591	735	0.845	0.684
2	0.583	0.529	772	519	0.781	0.77
3	0.637	0.458	646	611	0.794	0.637
4	0.476	0.494	917	633	0.757	0.712
5	0.735	0.559	441	456	0.914	0.925
6	0.682	0.573	687	582	0.864	0.802
7	0.712	0.479	482	557	0.921	0.848
8	0.609	0.644	741	447	0.848	0.866
9	0.649	0.612	700	543	0.87	0.877
10	0.717	0.704	534	359	0.916	0.949
11	0.65	0.528	670	537	0.883	0.907
12	0.667	0.525	665	633	0.871	0.837
13	0.574	0.584	846	447	0.782	0.798
14	0.758	0.595	505	420	0.862	0.783
15	0.431	0.519	1079	558	0.648	0.845
16	0.715	0.473	536	535	0.908	0.831
17	0.667	0.699	589	352	0.911	0.893
18	0.551	0.556	823	499	0.854	0.878
19	0.561	0.462	726	479	0.84	0.849
20	0.588	0.633	724	399	0.719	0.754
mean	**0.63**	**0.55**	**684**	**515**	**0.84**	**0.82**
SD	*0.085*	*0.086*	*157*	*98*	*0.073*	*0.081*

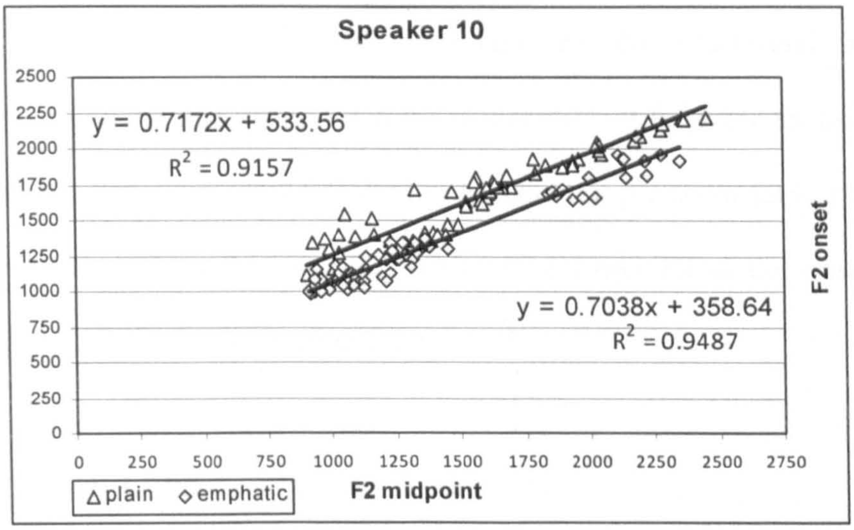
On the other hand, the y-intercept value for speaker 1 shows that the emphatic context has a higher value (at about 735 Hz) than that of the plain one (at about 591 Hz). For the majority of speakers, the y-intercept value is lower in the emphatic context. This agrees with the general pattern observed for the emphatic environment, suggesting that the emphatic context has lower F2 onset than the plain context. However, it is also possible for the emphatic context to have higher y-intercept values than the plain one as reported for speakers 1, 5 and 7 (see Table 5.1).

Fig. 5.2. The regression line for the LE slope for speaker 1



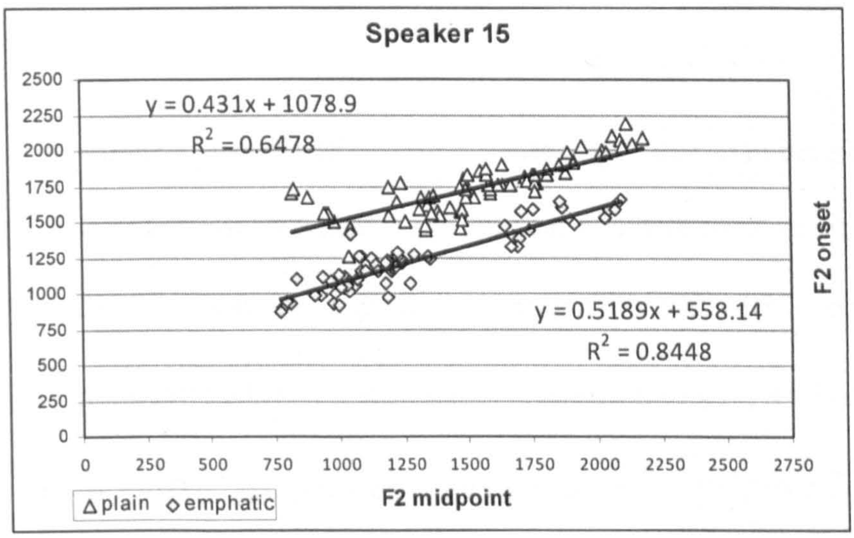
The slope difference between the plain and emphatic consonants is not considerable for other speakers. For instance, the emphatic context has a slightly lower slope value than the plain one for speakers 2, 9 and 10 (see appendix 5). In the case of speaker 10, the LE regression line for the plain context has almost the same degree of steepness as that for the emphatic one (see Figure 5.3). For this speaker, there is a similar slope value for the plain and emphatic consonants. Thus the regression lines of the slope indicate similar CV coarticulation for the plain and emphatic contexts as a result of having high slope values represented by steep lines (the plain slope = 0.717 and the emphatic slope = 0.704). Thus for some speakers CV coarticulation is not sensitive to context type (plain or emphatic). However, for speaker 10, the lower y-intercept for the emphatic consonant (359 Hz) than the plain (534 Hz) distinguishes the two contexts.

Fig. 5.3. The regression line for the LE slope for speakers 10



For some other speakers, the plain context is associated with lower slope values than those observed for the emphatic one (e.g., speakers 4, 8, 13, 15, 17) (see appendix 5). This has implications for inter-speaker variability since in this case the LE regression line is flatter for the plain than for the emphatic context, suggesting that the emphatic context shows more CV coarticulation than the plain one. For speaker 15, the LE slope is steeper for the emphatic context (0.519) than the plain one (0.431). This result is reflected in the shape of the regression line which is steeper for the emphatic context than for the plain one (see Figure 5.4). This is an indication of the fact that there is more emphatic-vowel coarticulation than plain-vowel coarticulation. The plain-emphatic distinction is manifest in the substantially low y-intercept value for the emphatic context for speaker 15. Furthermore, the high R^2 for the emphatic context in comparison with the plain one indicates the degree of good correlation between different tokens of the same speaker and thus small intra-speaker variability for the emphatic context. The y-intercept value for speaker 15 is almost twice as high in frequency in the plain context (1079 Hz) than in the emphatic one (558 Hz.). This could be indicative of the role played by the LE parameter of y-intercept in successfully distinguishing between the plain and emphatic consonants when the role of the LE slope is inconsistent for some speakers. This is because the low y-intercept reflects the presence of the secondary articulation of the emphatics given that it is suggestive of a lower F2 at the onset of the vowel following the emphatic consonant.

Fig. 5.4. The regression line for the LE slope for speaker 15



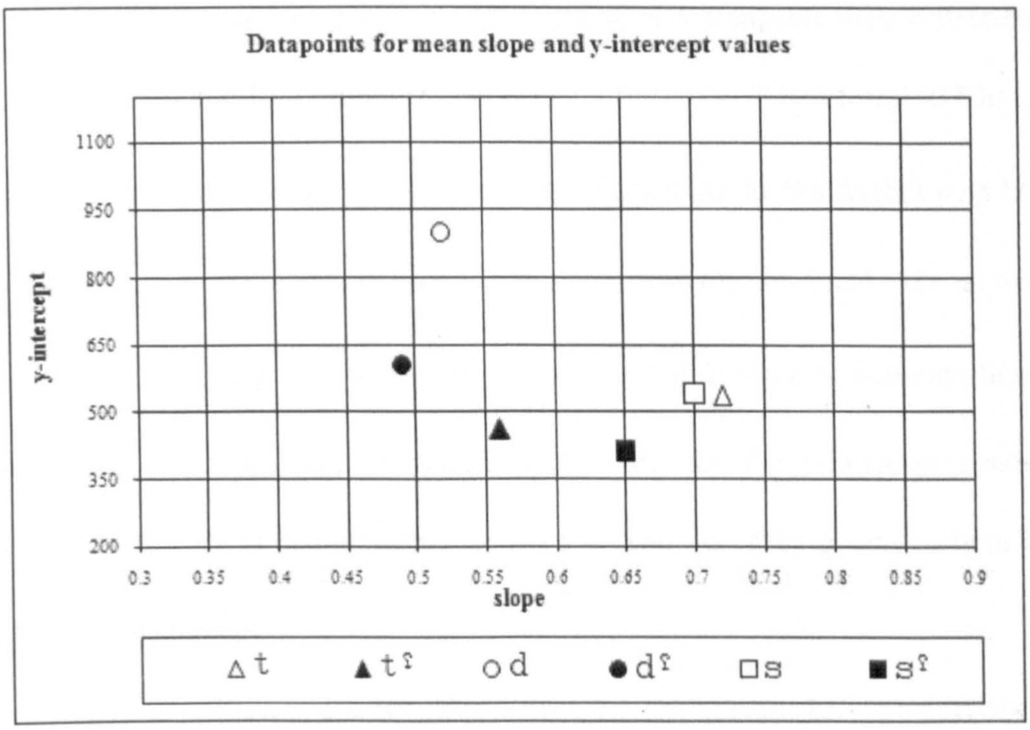
5.3. LE parameters for different plain and emphatic consonants

An investigation of LE slope and y-intercept of each of the plain and emphatic consonants is also carried out in order to shed some light on the behaviour of different classes of consonants. In this case, datapoints are formed for the data representing each consonantal type (see appendix 7a). Generally speaking, the three emphatic consonants /tˤ sˤ dˤ/ have flatter slopes than their plain counterparts /t s d/; flat slopes are indicators of coarticulatory resistance to vowel articulation. Moreover, the slope difference within the /t/-/tˤ/ contrast is greater than that within the /s/-/sˤ/ and /d/-/dˤ/ contrasts (see appendix 6b for mean slope values). The role of LE slope could therefore depend on the consonantal type as the voiceless stops /t/ and /tˤ/ have slope values that better reflects the plain-emphatic distinction than those obtained from the fricative and voiced stop contrasts. An independent sample t-test confirms this by showing a highly significant slope difference between /t/ and /tˤ/ ($t(38) = 4.499$, $p < 0.001$) while it is non-significant between /s/ and /sˤ/ ($t(38) = .509$, $p > 0.05$) and between /d/ and /dˤ/ ($t(38) = 1.438$, $p > 0.05$).

The emphatic context has a lower y-intercept value than the plain one; this is true for all consonantal types. An independent sample t-test shows that the y-intercept difference is highly significant between the /d/-/dˤ/ contrast ($t(38) = 5.547$, $p < 0.001$) while it is significant between the /s/-/sˤ/ contrast ($t(38) = 2.888$, $p < 0.05$), and not significant between the /t/-/tˤ/ contrast ($t(38) = 1.838$, $p > 0.05$). This enhances the role of y-intercept in the /d/-/dˤ/ and /s/-/sˤ/ distinctions when the slope difference is not as considerable as that of the y-intercept.

Figure 5.5 represents datapoints of the LE slope (on the x axis) and y-intercept (on the y axis). This is done in order to find out how the LE parameters for plain and emphatic consonants of different types are represented. The emphatic consonants have variable results with respect to their slope values; the highest slope is reported for /sˤ/ (0.65), then /tˤ/ (0.56) and finally /dˤ/ (0.49). According to these results, /sˤ/ seems to have stronger CV coarticulation than /tˤ/ and /dˤ/ as reflected in the flatness of the regression line of the slope which appears to be flatter for the voiced emphatic stop /dˤ/ (see also appendix 7a). This suggests greater F2 difference between the onset and midpoint in the context of /dˤ/ in comparison with that in the /tˤ/ and /sˤ/ contexts.

Fig. 5.5. Slope by y-intercept for plain and emphatic consonants



A one way Anova test shows that the difference is significant between the slope for the emphatic consonants ($F(2, 57) = 13.37$, $p < 0.001$). According to the results of Bonferroni post hoc tests, the /tˤ/-/dˤ/ difference is significant and the /dˤ/-/sˤ/ difference is highly significant while the /tˤ/-

/sˤ/ difference is non-significant (see Table 5.2). For the voiced stop /dˤ/, formant frequencies start earlier than the case of other consonants; this will cause the formant onset to be closer to the consonant, thus reflecting obviously the effect of the consonant. This leads to high F2 difference between the onset and midpoint of the vowel and a lesser degree of CV coarticulation.

The slope order for the plain consonants shows that /t/ has the highest slope (0.72), followed by /s/ (0.70) and /d/ (0.52) respectively. Results from one way Anova show that the difference is significant between the slope for the plain consonants ($F(2, 57) = 28.303$, $p < 0.001$). These results, in turn, are helpful in estimating the degree of CV coarticulation alongside their reflections on the shape of the LE regression line (see appendix 6a). Therefore, /d/ has a flatter slope than the slope for /t/ and/s/. According to Bonferroni post hoc results, the slope difference is highly significant between /t/ and /d/ as well as between /d/ and /s/ while the /tˤ/-/sˤ/ difference is non-significant (see Table 5.2). This pattern, which is the same for the y-intercept results, indicates that /d/ is distinguished from /tˤ/ and /sˤ/ by means of both its slope and y-intercept.

A one way Anova test shows that the y-intercept difference between different emphatic consonants is significant ($F(2, 57) = 11.472$, $p <.001$). According to Bonferroni post hoc results, the y-intercept difference is significant between /tˤ/ and /dˤ/ as well as between /dˤ/ and /sˤ/ whereas it is non-significant between /tˤ/ and /sˤ/ (see Table 5.2). The same pattern of significance is reported for their plain counterparts. This is because a one way

Anova shows that the y-intercept difference between different plain consonants is significant ($F(2, 57) = 21.287$, $p < .001$) (see also Bonferroni post hoc results in Table 5.2). The statistical results for the y-intercept are similar to those for the slope in the sense that they show that the emphatics /tˤ/ and /sˤ/ are characterised by similar slopes and y-intercepts and differ from the voiced /dˤ/.

Table 5.2. Results from Bonferroni post hoc tests for slope and y-intercept[10]

Bonferroni post hoc tests for slope			
plain	p value	emphatic	p value
/t/-/d/	< .001	/tˤ/-/dˤ/	< .05
/t/-/s/	> .05	/tˤ/-/sˤ/	> .05
/d/-/s/	< .001	/dˤ/-/sˤ/	< .001
Bonferroni post hoc tests for y-intercept			
plain	p value	emphatic	p value
/t/-/d/	< .001	/tˤ/-/dˤ/	< .001
/t/-/s/	> .05	/tˤ/-/sˤ/	> .05
/d/-/s/	< .001	/dˤ/-/sˤ/	< .001

Likewise, the plain consonants /t/ and /s/ have close slope and y-intercept values as compared to the voiced consonant /d/. This seems to indicate, regardless of emphasis, that the state of voicing could affect LE parameters since the voiceless consonants, although they have different manners of articulation, have similar slopes and y-intercepts. The emphatic /dˤ/ behaves differently from /tˤ/ although they both share the same manner of articulation and similarly /d/ and /t/ differ from each other.

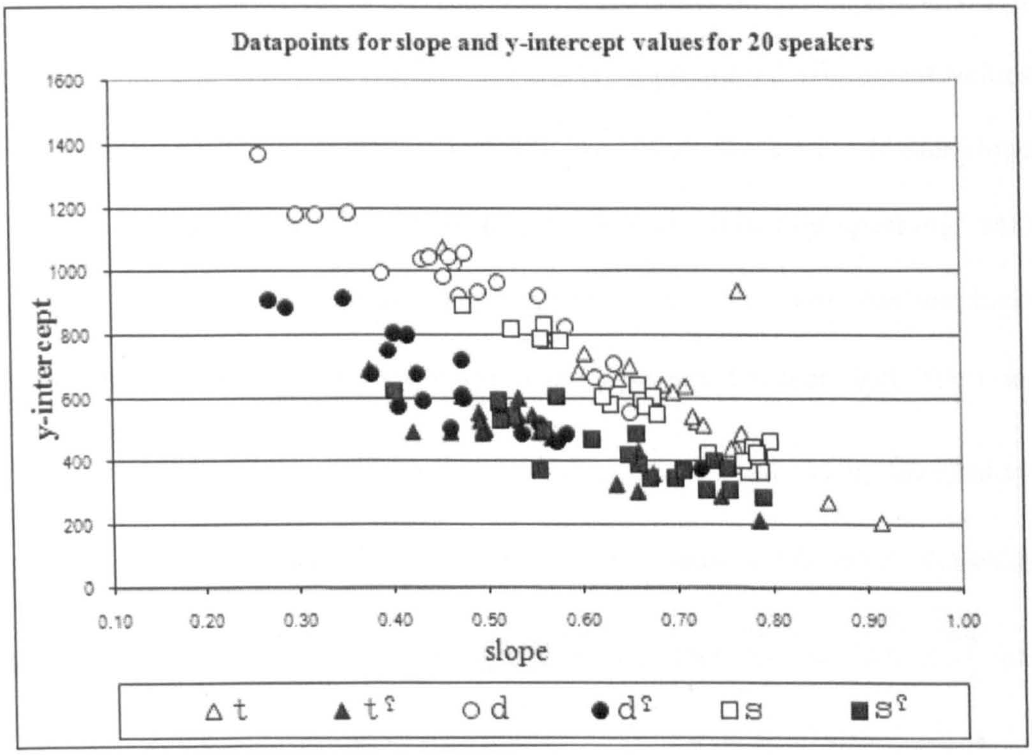
[10] Comparison is made between different plain contexts and between different emphatic contexts

On the other hand, the y-intercept is not as efficient as the slope in the distinction between /t/ and /tˤ/ as for both consonants the values are close to 500 Hz (see Figure 5.5). The datapoints for /t/ and /s/ are very close to each other, compared to that for /d/, indicating the similar y-intercept and slight slope difference for /t/ and /s/. The three emphatic consonants /tˤ dˤ sˤ/ have distinct slope values, but close y-intercept values for /tˤ/ and /sˤ/. The slope value for /dˤ/ is relatively different from those of the other emphatics as illustrated by the datapoints.

The inconsistency of the slope results is also detected in the CV coarticulatory patterns of the plain /s/ and emphatic /sˤ/ as shown by results for all speakers (see Fig. 5.6), but with a lesser degree than the /d/-/dˤ/ contrast and with a greater extent than the /t/-/tˤ/ contrast. It is clear that the slope values for the plain /s/ overlap with those for the emphatic /sˤ/ (see Figure 5.6). Results from y-intercept achieved more consistency than the slope results.

Data for different consonantal types from all speakers show that the plain and emphatic consonants can have inconsistent slope and y-intercept values as for some speakers the slope and y-intercept values can be higher for the emphatic context than for the plain context (see shaded boxes in appendix 6b). This does not agree with the general pattern which shows that the emphatic context is characterised by a lower slope and y-intercept than the plain context. Furthermore, the lack of consistency is best shown by the slope results of /d/ and /dˤ/ and the y-intercept results for /t/ and /tˤ/. This seems to be the reason why the /d/-/dˤ/ contrast is best distinguished by their y-intercept while the /t/-/tˤ/ contrast is best distinguished by the slope.

Fig 5.6. Slope by y-intercept for plain and the emphatic consonants for all speakers



The inconsistent slope and y-intercept results for some speakers seem to be the source of the overlap between the plain and emphatic contexts (see Figure 5.6). There is an overlap between the datapoints for both /d/ and /dˤ/ on the slope axis whereas most data points for the /t/-/tˤ/ and /s/-/sˤ/ contrasts indicate a higher slope for the emphatic context than for the plain one (see Figure 5.6 above). This is indicative of the slope sensitivity to the consonantal type.

5.4. Summary of locus equation results

The group result based on data from all speakers has revealed that the slope and y-intercept values are lower for the emphatic environment as compared to the plain one. However, data from different speakers exhibits inconsistent results in terms of the effect of the emphatic consonants on LE parameters. For some speakers, the emphatic context has lower slope and/or y-intercept values than the plain one, but with varying degrees. For other speakers, a higher slope and y-intercept is reported for the emphatic context. Generally speaking, with respect to the effect of the consonantal type on LE parameters, the emphatic consonants /tˤ sˤ dˤ/ have lower slope and y-intercept values than their non-emphatic counterparts /t s d/, with the /t/-/tˤ/ contrast having the greatest slope difference followed by the /s/-/sˤ/ and /d/-/dˤ/ contrasts respectively. The greatest y-intercept difference is reported between /d/ and /dˤ/.

Chapter Six

Duration and Intensity Results

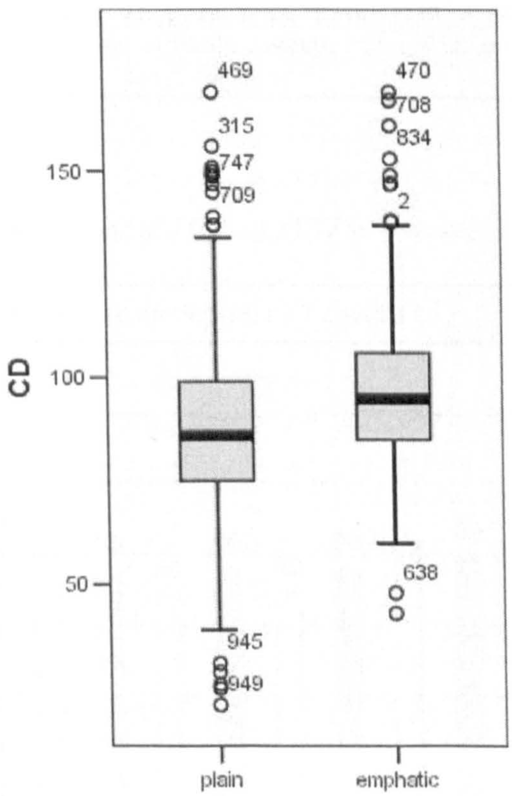
6.0. Introduction

This chapter investigates how acoustic parameters related to duration and intensity differentiate between the plain and emphatic consonants. It focuses on the role of closure duration (CD) and voice onset time (VOT) in the /t/-/tˤ/ distinction in addition to the effect of emphasis on the duration of the following vowel in the context of different plain and emphatic consonantal types. The duration and intensity of /sˤ/ and /s/ are measured so as to assess the claim in the literature concerning the longer duration for /sˤ/ than /s/ as a function of the greater intensity for /sˤ/ than /s/.

6.1. Closure duration (CD) for /t/ and /tˤ/

Closure duration results show that the emphatic /tˤ/ is associated with longer closure duration than the plain /t/. The mean CD values based on all vocalic contexts are 88 and 98 ms for /t/ and /tˤ/ respectively. The difference between the two contexts is significant according to the non-parametric independent sample t-test, Mann-Whitney test ($z = -7.613$, $p<0.001$). The overall distribution of data shows the tendency for CD to be longer for the emphatic /tˤ/ than the plain /t/ although there is a great deal of overlap between the two contexts (see Figure 6.1). The boxplots in Figure 6.1 show that the median is longer for the /tˤ/ CD than for the /t/ CD. The distribution of the 50% of cases show a tendency for the emphatic context to be longer than the plain context with some overlap between the two contexts. Both top and bottom whiskers show that the emphatic context has longer CD than the plain context with some overlap. The top whiskers illustrate that the distribution of the data is similar between both contexts. The bottom whiskers show that the shape of the distribution is different from the top whiskers. The bottom whiskers reveal less overlap between the two contexts than the top whiskers. There are some extreme values particularly for the top values.

Fig. 6.1. Closure duration for /t/ and /tˤ/

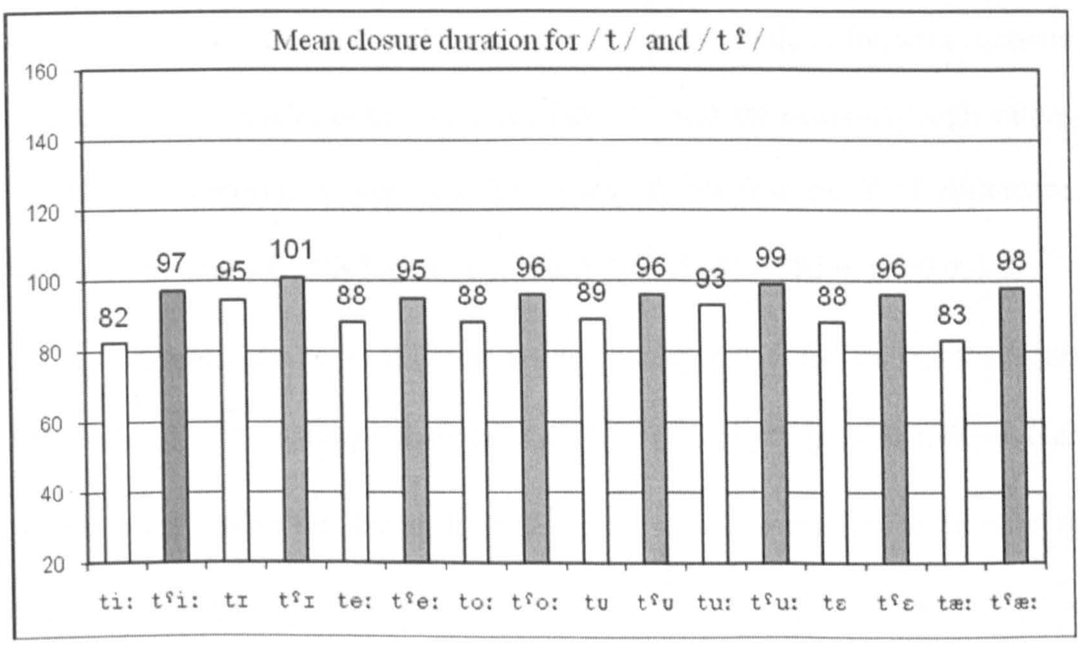


The higher CD difference can be observed for the /t/-/tˤ/ contrast in all vocalic contexts, but with varying degrees of increase (see Table 6.1). The CD difference between the two contexts is greater in the case of /iː/ and /æː/ and becomes smaller for the other vocalic contexts (see Fig. 6.2).

Table 6.1. Descriptive statistics for CD values for /t/ and /tˤ/

V	/iː/		/ɪ/		/eː/		/oː/	
C	tˤ	t	tˤ	t	tˤ	t	tˤ	t
mean	82	97	95	101	88	95	88	96
min	25	72	44	69	21	43	26	69
max	150	153	162	161	169	173	145	138
SD	24	18	21	19	23	22	24	17
V	/ʊ/		/uː/		/ɛ/		/æː/	
C	tˤ	t	tˤ	t	tˤ	t	tˤ	t
mean	89	96	93	99	88	96	83	98
min	39	65	40	68	40	48	49	66
max	133	137	156	167	150	149	120	138
SD	19	16	21	19	21	18	16	15
The mean CD duration for all vocalic contexts: /t/ = 88 ms and /tˤ/ = 98 ms								

Fig. 6.2. Mean CD values in the context of /t/ and /tˤ/ in 8 vocalic contexts



6.2. Voice Onset Time (VOT) for /t/ and /tˤ/

An investigation of VOT for the Libyan Arabic /t/-/tˤ/ contrast shows that VOT is longer for the plain /t/ (mean=35 ms) than for the emphatic /tˤ/ (mean=18 ms). Plain /t/ is slightly aspirated given that audible aspiration is determined by Laver (1994) to occur between 25-30 ms and exhibits a longer lag than /tˤ/. In spite of some overlap in the VOT values between the two contexts, the overall distribution of data shows that the emphatic /tˤ/ tends to have shorter VOT than /t/ as it is clear from the median, the boxes and whiskers of the boxplots (see Figure 6.3). The top whisker for the emphatic /tˤ/ shows that 25% of the VOT values for /tˤ/ overlap with those of the plain /t/, and the bottom whisker of the plain /t/ shows that 25% of VOT values for /t/ overlap with those of /tˤ/. The boxplot for the emphatic context shows that the middle 50% of values represented by the box have shorter VOT values than those of the plain context. There are outliers for both contexts as marked by the circles in the boxplots; these outliers are extremely high values for the two contexts. A one way Anova test shows that the VOT difference between /t/ and /tˤ/ is highly significant ($F(1, 943) = 592.6$, $p < 0.001$).

Likewise, results for different vocalic contexts demonstrate that the mean VOT value for /t/ is longer than that for /tˤ/ (see Figure 6.4); an independent sample t-test conducted for each vowel context shows that the difference is highly significant (see Table 6.2). The shaded boxes in Table 6.2 indicate that a non-parametric version of the independent sample t-test, Mann-Whitney is applied.

Fig. 6.3. VOT for /t/ and /tˤ/

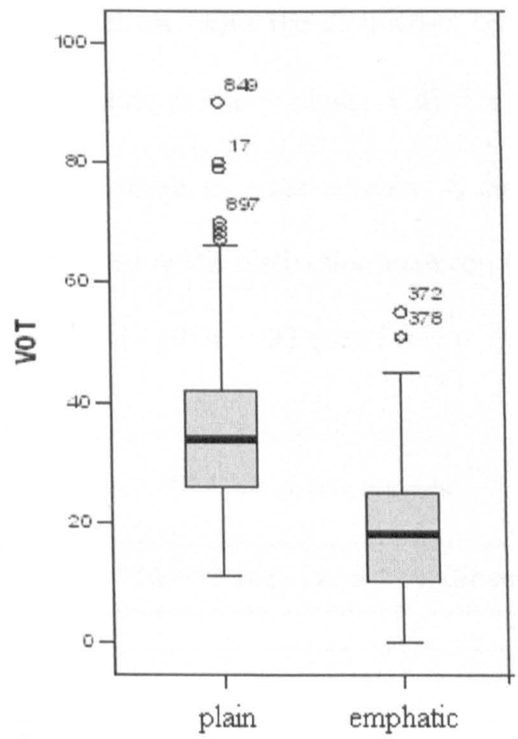


Table 6.2. Independent sample t-tests for VOT differences between /tˤ/ and /tˤ/

vowel context	independent sample t-test
/i:/	(z = -8.682, p < 0.001)
/ɪ/	(t(111) = 7.888, p < 0.001)
/e:/	(t(115) = 9.012, p < 0.001)
/o:/	(t(118) = 8.707, p < 0.001)
/ʊ/	(t(117) = 9.212, p < 0.001)
/u:/	(t(117) = 7.798, p < 0.001)
/ɛ/	(z = -6.953, p < 0.001)
/æ:/	(t(118) = 8.093, p < 0.001)

The highest mean VOT for /tˤ/ is 21 ms when adjacent to /i:/ while mean VOT for /t/ has slight aspiration for most vocalic contexts. Moreover, mean VOT for /t/ is 51 ms in the context of /i:/, signalling strong aspiration when compared to VOT in the other vowel contexts and suggesting that both vowel height and vowel length affect VOT. The high VOT values for /t/ in the context of the high front vowel increases the distinction between the voiceless /t/-/tˤ/ opposition (see Table 6.3 and Figure 6.4) due to the wider VOT difference in this context compared to other vowels. A smaller range for the emphatic VOT does not allow as much distinction between the different vocalic contexts as the wider range for the plain VOT (see Table 6.3).

Fig. 6.4. Mean VOT values for /t/ and /tˤ/ in 8 vocalic contexts

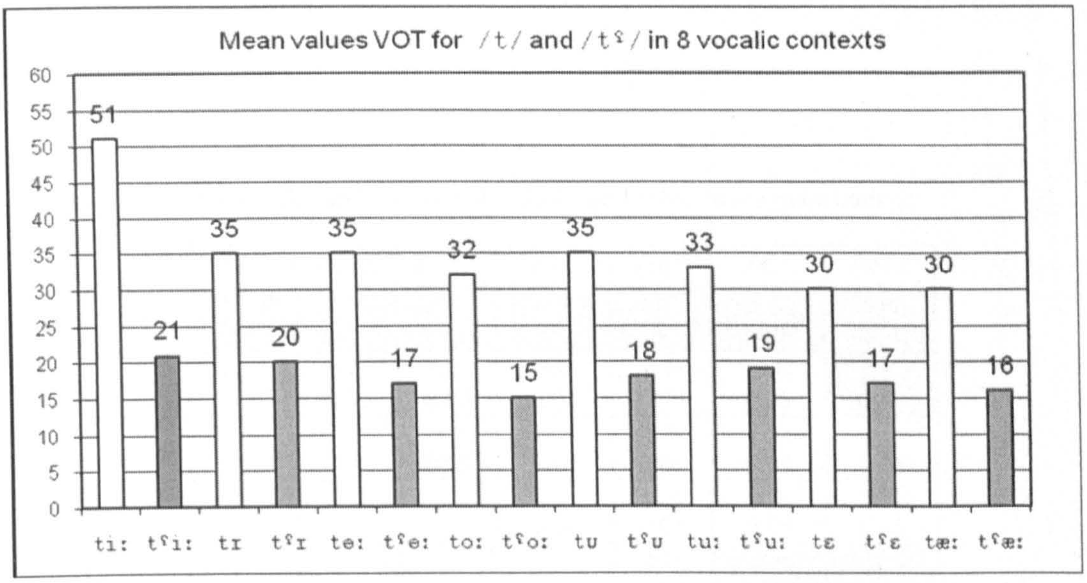


Table 6.3. Descriptive statistics for VOT values for /t/ and /tˤ/

V	/i:/		/ɪ/		/e:/		/o:/	
C	t	tˤ	t	tˤ	t	tˤ	t	tˤ
mean	51	21	35	20	35	17	32	15
max	90	45	54	55	56	44	47	29
min	23	0	18	0	19	0	15	0
SD	14	12	9	12	9	10	8	8
V	/ʊ/		/u:/		/ɛ/		/æ:/	
C	t	tˤ	t	tˤ	t	tˤ	t	tˤ
mean	35	18	33	19	30	17	30	16
max	56	51	59	42	59	33	58	33
min	14	0	15	0	17	0	11	0
SD	9	11	9	10	10	8	9	8

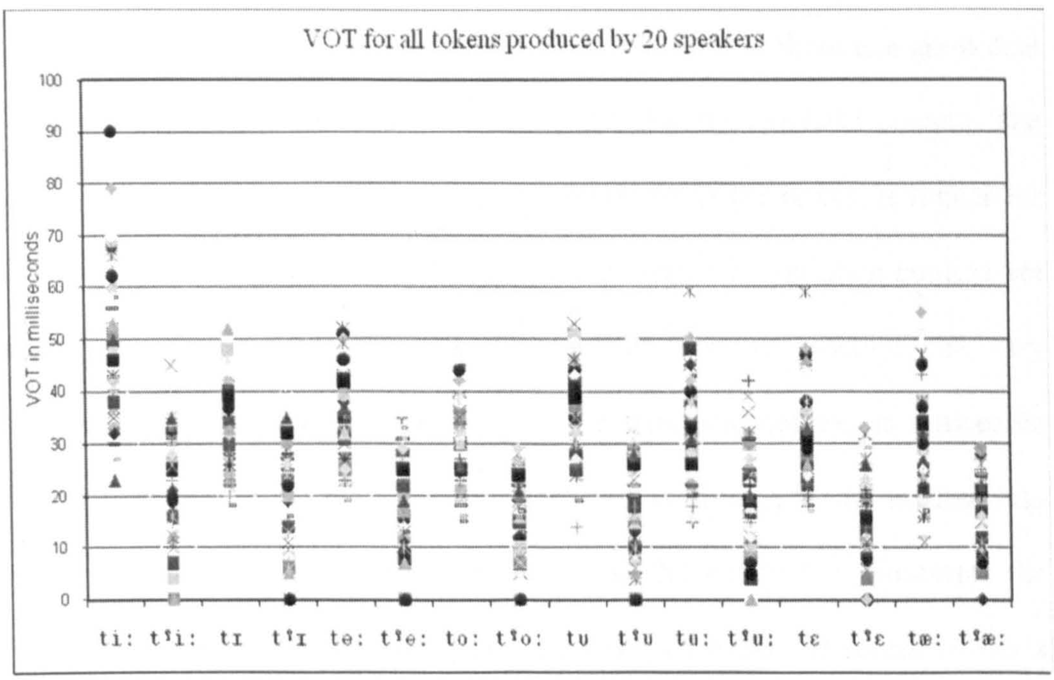
According to a one way Anova test, the VOT difference across different vocalic contexts is not significant in the emphatic context ($F (7, 463) = 1.12$, $p > 0.05$) while the difference across different vocalic contexts is significant in the plain context ($F (7, 466) = 24.02$, $p < 0.001$). According to The Tukey post hoc test (see Table 6.4), in the plain context the difference between VOT in the context of the high front long vowel and other vocalic contexts is highly significant (see shaded and italic boxes in Table 6.4). The VOT difference between the other vocalic contexts is not significant apart from some instances which show only a significant difference (see shaded and bold boxes in Table 6.4).

Table 6.4. Statistical results for VOT between different vowels in the plain context

	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
/i:/	*$p < 0.001$*	*$p < 0.001$*	*$p < 0.001$*	*$p < 0.001$*	*$p < 0.001$*	*$p < 0.001$*	*$p < 0.001$*
/ɪ/		$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	**$p < 0.05$**
/e:/			$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
/o:/				$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
/ʊ/					$p > 0.05$	**$p < 0.05$**	**$p < 0.05$**
/u:/						$p > 0.05$	$p > 0.05$
/ɛ/							$p > 0.05$

It is interesting to note that the minimum value for VOT for /tˤ/ is zero across all vocalic contexts (see Table 6.3 above), indicating that voicing for the following vowel can coincide with the release of the emphatic stop. Since aspiration is thought to reflect the degree of glottal opening at the release of the stop (Kim 1970), these values suggest a smaller degree of opening of the glottis in the production of the emphatic consonants. VOT values for /t/ never fall below 11 ms. However, there is a considerable overlap in the VOT values for plain and emphatic consonants in all vocalic contexts (VOT for /t/ ranges from 11 to 90 ms while that for /tˤ/ ranges from 0 to 55 ms), so that some values from both consonants can fall in the long lag region (see Figure 6.5).

Fig. 6.5. VOT distribution for /t/ and /tˤ/ in 8 vocalic contexts

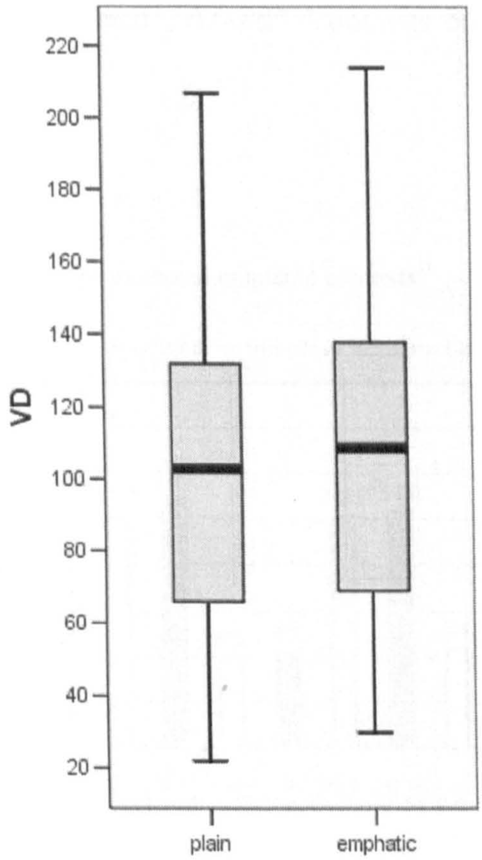


Both the plain and emphatic contexts have unaspirated and slightly aspirated tokens, but only some tokens of the plain /t/ can be associated with considerable aspiration. According to Kim (1970), 10 ms of voicing lag is observed for unaspirated stops, 35 for stops with slight aspiration and 90 for heavy aspiration. Despite this overlap, the mean values in every vocalic context suggest that VOT can distinguish /t/ from /tˤ/ in Libyan Arabic.

6.3. Vowel duration in the plain and emphatic contexts

This section examines the effect of emphasis on the duration of the following vowel. General results are first assessed to obtain a comprehensive view of such an effect. The overall results show that the mean VD in the emphatic context (104 ms) is longer than that in the plain one (99 ms). Although the mean difference seems to be small, the difference is highly significant according to one way Anova ($F(1, 2737) = 15.227$, $p < 0.001$). The output from boxplots provides information about the distribution of vowel duration in the plain and emphatic contexts (see Figure 6.6). It is clear that there is a great deal of overlap between VD in the plain context and VD in the emphatic context. The median, which is represented by a line in the middle of the boxes, is higher for the vowels in the emphatic context than for the vowels in the plain context yet the median difference between the two contexts does not seem to be very considerable. The position of the box for the emphatic context is noticeable different from that of the plain context. Each box is divided by the median into two parts, namely the top and bottom parts and the whole box represents the range of the middle 50% of cases. The general distribution of scores shows a tendency for vowel duration to be higher in the emphatic context than in the plain context. The top whiskers which represent the top 25% of the variable' largest values tend to be higher in the emphatic context as compared to the plain context and so do show the bottom 25% of smallest values as represented by the bottom whiskers.

Fig. 6.6. Vowel duration in the plain and emphatic contexts



Results for different vowels demonstrate that the vowel /eː/ is different from other vowels in that it is slightly shorter in the emphatic than in the plain environment. The vowel duration difference between the plain and emphatic context is, to some extent, higher for the vowels /iː ɪ oː/ compared to other vowels in which the difference is comparatively smaller between the two contexts (see Figure 6.7).

The assessment of the effect of emphasis on vowel duration focuses also on results for different plain-emphatic contrasts. This is to observe any effect that may be induced by the consonantal type. Table 6.5 presents vowel duration for different consonantal types in different vocalic contexts. The mean difference shows that vowel duration is longer in the emphatic than in the plain context across all consonantal types yet this difference is not considerable particularly in the context of the /s/-/sˤ/ and /d/-/dˤ/contrasts compared to the /t/-/tˤ/ contrast.

Fig. 6.7. Mean VD for 8 vowels in the plain and emphatic contexts[11]

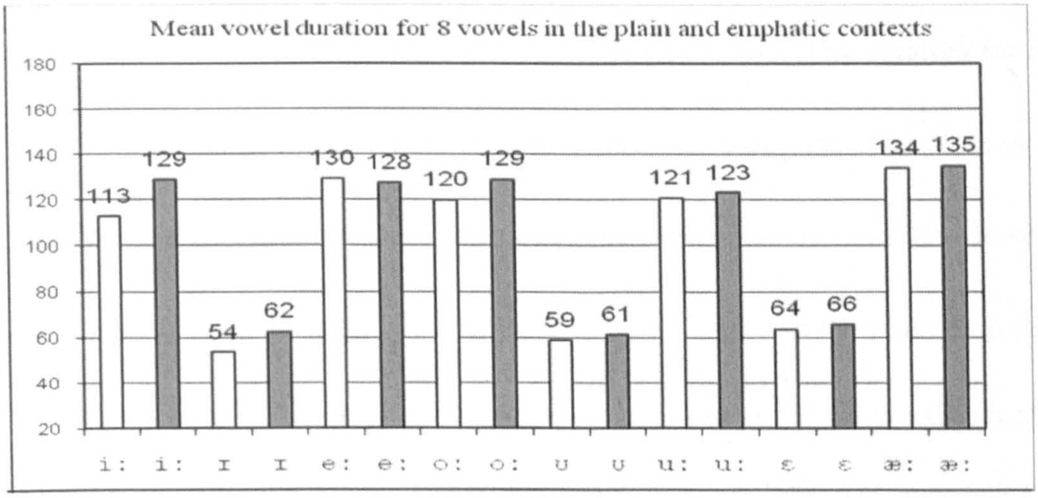


Table 6.5. Mean VD in the context of different plain and emphatic consonantal types

Vowel	/t/	/tˤ/	/s/	/sˤ/	/d/	/dˤ/
/iː/	106	129	112	121	121	137
/ɪ/	49	56			57	68
/eː/	123	132	121	122	147	130
/oː/	141	146	124	129	97	114
/ʊ/	56	65	51	56	69	63
/uː/	117	120	111	118	135	133
/ɛ/	64	66	62	63	65	68
/æː/	122	129	132	131	149	146
Group mean	98	106	102	106	105	108

The higher vowel duration in the emphatic context of /tˤ/ than in the plain context of /t/ is reported for all vowels. The VD difference between the

[11] White columns represent the plain context and the dark ones the emphatic context.

emphatic and plain contexts is consistent across all vowel contexts, but varies in magnitude. The largest difference is found in the context of /iː/, but becomes smaller in the remaining contexts. For the /s/-/sˤ/ contrast, the overall mean durational difference becomes smaller as compared to that in the case of the /t/-/tˤ/ contrast, and varies with the vowel context. For the /d/-/dˤ/ contrast, different vowel contexts yield inconsistent results. The duration for /iː ɪ oː/ is higher in the emphatic context than in the plain one. The same is true for /ɛ/, but the difference in VD between the two contexts is smaller. However, the duration for /eː ʊ uː æː/ is reported to be longer in the plain than in the emphatic context. The lack of consistency between different vocalic contexts might play down the role of VD in the distinction between /d/ and /dˤ/ and might not allow for any association between the effect of emphasis and the increase in vowel duration especially if considering that the overall results for this contrast demonstrate that the difference is not significant as discussed later in this section.

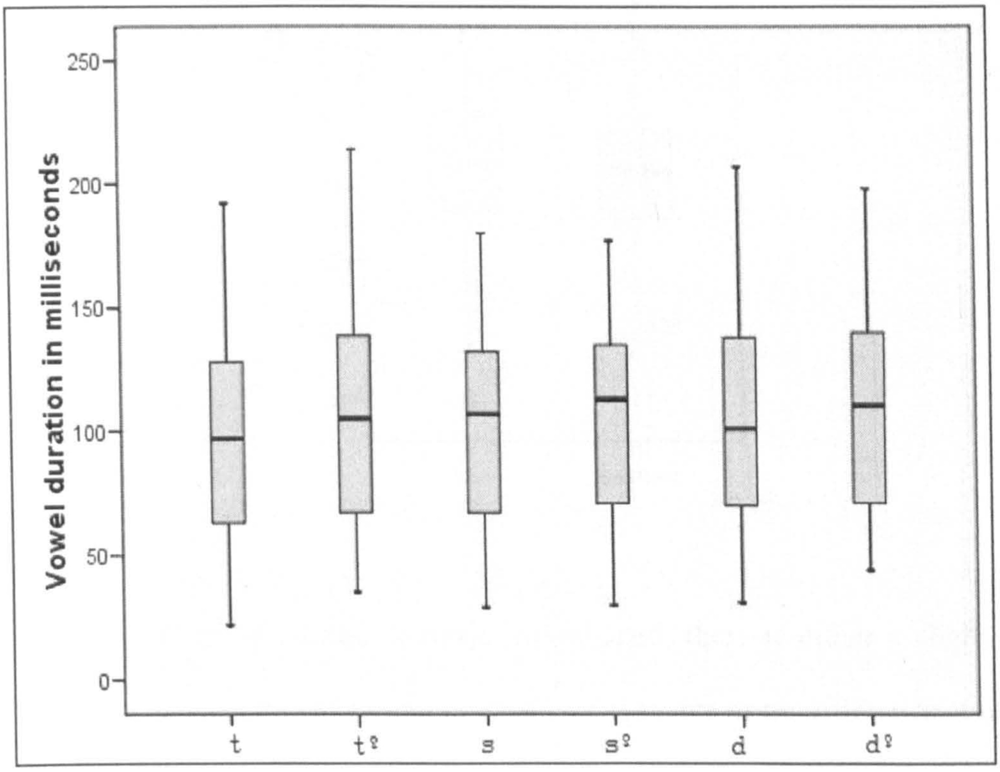
It is clear from Table 6.5 that the vowel duration difference is slight and non-significant across different consonantal types in the emphatic context; this is confirmed by results from one way Anova ($F(2, 1368) = 1.237, p > 0.05$). On the other hand, the same test shows that the vowel duration difference is significant across different consonantal types in the plain context ($F(2, 1365) = 8.758, p < 0.001$). A Bonferroni post hoc tests show that the difference is significant between the vowel duration in the context of /t/ and /d/ ($p < 0.001$), but not significant between the /t/ and /s/ contexts and /s/ and /d/

contexts ($p > 0.05$). Generally speaking, the shortest VD is reported in the /t/ context. Thus the significant VD difference between the /t/ and /tˤ/ contexts discussed later in this section may be attributed to the presence of aspiration for /t/ rather than a lengthening effect of the empathic context of /tˤ/.

According to one way Anova, the difference between the vowel in the emphatic context of /tˤ/ is significantly longer than the vowel in the plain context of /t/ ($F(1, 952) = 15.146$, $p < 0.001$). On the other hand, the same test shows that the VD difference between the plain and emphatic contexts is not significant in the case of the /s/-/sˤ/ contrast ($F(1, 834) = 3.196$, $p > 0.05$) and the /d/-/dˤ/ contrast ($F(1, 947) = .918$, $p > 0.05$).

The overall distribution of data provides information about the overlap between the plain and emphatic contexts across different consonantal types although the median is higher for the emphatic contexts than for the plain contexts (see Fig. 6.8). However, the distribution of data shows that the boxes which represent the middle 50% of cases and top and bottom whiskers which represent the other 50% of cases do not have a consistent pattern across different consonantal contexts. The majority of values tend to be higher for the vowel in the context of /tˤ/ than for that in the context of /t/. In the case of the /s/-/sˤ/ and /d/-/dˤ/ contrasts, the overall distribution of VD is different given that the boxes which represent 50% of cases show that VD is similar for the plain and emphatic contexts. Furthermore, the whiskers show similar tendencies and the longest vowel duration values seem to be associated with the plain context. This overall distribution of data is supported by the statistical results reported in this section as they show that the VD difference between the plain and emphatic contexts is not significant in the case of the /s/-/sˤ/ and /d/-/dˤ/ contrasts. It should also be noted that variation in vowel duration in both the plain and emphatic contexts is observed (see appendix 9).

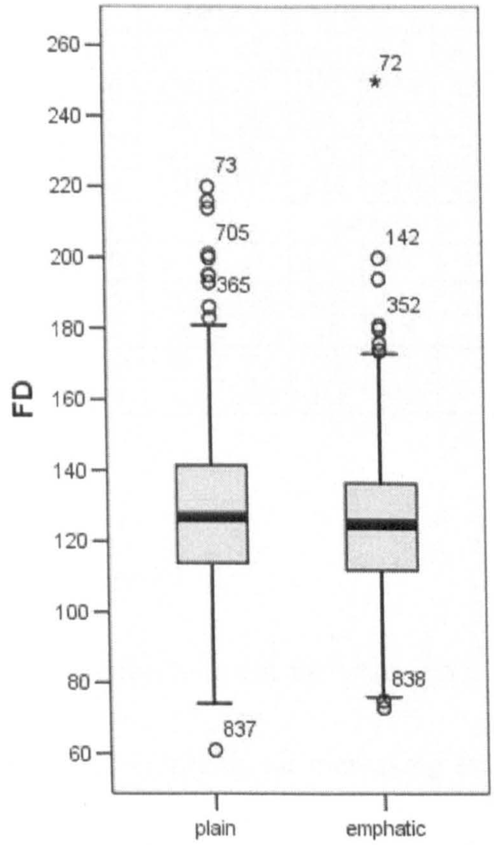
Fig 6.8. Vowel duration in different consonantal contexts



6.4. Fricative duration for /s/ and /sˤ/

The overall distribution of data shows that fricative duration for the plain /s/ and the emphatic /sˤ/ are very similar for both sounds (see Figure 6.9). There is an overlap between the two contexts, and the median difference is slight. Results from the non-parametric version of the independent sample t-test, Mann-Whitney test shows that there is no statistical difference between the fricative duration for the two fricatives ($z = -1.494$, $p > 0.05$).

Fig. 6.9. Duration for /s/ and /sˤ/



In all seven vocalic contexts investigated, there is either a slight mean difference between the plain and emphatic consonants or no difference at all (see Table 6.6). The tendency is found for /sˤ/ to have shorter duration than /s/ across all vocalic contexts apart from the /iː/ context. The biggest durational difference between /sˤ/ and /s/ is reported in the /eː/ context, followed by /ʊ/ and /æː/ respectively while the difference is negligible in the contexts of /iː oː ɛ/ and there is no difference in the /uː/ context (see Table 6.6).

Table 6.6. Descriptive statistics for FD for /s/ and /sˤ/

V	/iː/		/eː/		/oː/		/u/	
C	s	sˤ	s	sˤ	s	sˤ	s	sˤ
mean	139	140	134	127	131	130	128	123
SD	22	27	25	20	24	17	22	18
min	87	87	80	76	83	89	76	85
max	186	250	220	173	216	174	200	169
V	/uː/		/ɛ/		/æː/			
C	s	sˤ	s	sˤ	s	sˤ		
mean	125	125	114	113	126	122		
SD	24	20	19	18	19	18		
min	75	76	61	73	76	77		
max	195	194	193	160	167	157		

6.5. Intensity for /s/ and /sˤ/

The intensity difference between the plain /s/ and the emphatic /sˤ/ does not show any effect of emphasis on increasing the intensity of /sˤ/. For all vocalic contexts, the intensity ranges from 39 to 76 dB in the plain context and from 39 to 77 dB in the emphatic context. This considerable variation, however, does not seem to be important in separating the plain /s/ from the emphatic /sˤ/. The range and mean are similar for both contexts across seven vocalic contexts (see Table 6.7). Results from the non-parametric test, Mann-Whitney test shows that there is no statistical difference between the intensity of /s/ and /sˤ/ ($z = -775$, $p > 0.05$). The overall distribution of intensity for /s/ is similar to that for /sˤ/as illustrated by the general shape of the boxplots (see Figure 6.10) apart from the median which is slightly higher for the plain than for the emphatic context. There are some extreme high intensity values for both contexts as illustrated by the circles above the top whiskers.

Fig. 6.10. Intensity in dB for /s/ and /sˤ/

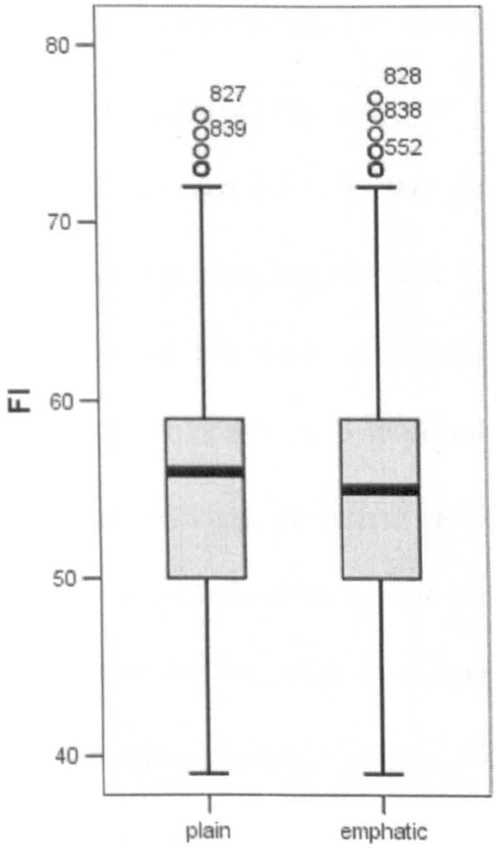


Table 6.7. Descriptive statistics for the intensity of /s/ and /sˤ/

V	/i:/		/e:/		/o:/		/ʊ/	
C	s	sˤ	s	sˤ	s	sˤ	s	sˤ
mean	55	56	55	55	55	54	54	53
SD	7	7	7	7	6	7	7	8
min	39	39	41	40	46	39	39	39
max	76	77	75	73	72	73	73	74
V	/u:/		/ɛ/		/æ:/			
C	s	sˤ	s	sˤ	s	sˤ		
mean	54	54	55	55	55	55		
SD	7	8	9	7	7	7		
min	41	40	43	40	40	42		
max	68	76	70	75	74	74		

6.6. Acoustic temporal compensation for /tˁ/ and /tˤ/

The CD and VOT results reported for /t/ and /tˤ/ in this chapter tend to indicate an inverse relation between CD and VOT (i. e., VOT is longer for /t/ than /tˤ/ whereas CD is longer for /tˤ/ than for /t/). These results are consistent in all vowel contexts for both CD and VOT.

The effect of emphasis on increased vowel duration in the context of the emphatic /tˤ/ seems to be triggered by a temporal compensation between different acoustic parameters. Although this effect varies across different vocalic contexts, it is consistent for all vowels. Results from this study may suggest that VOT covaries with VD in that the long VOT for the plain /t/ occupies part of the vowel by delaying the start of voicing and the formant frequencies of the following vowel. Accordingly, there seems to be an inverse relationship between VOT and VD; VOT is longer for the plain /t/ than for the emphatic /tˤ/ while vowel duration is longer in the emphatic than in the plain environment.

Further evidence for the effect of VOT on vowel duration may be deduced from different results across different vocalic contexts. This is because for some vocalic contexts where the VOT difference between the plain and emphatic context is large the vowel duration difference is also large and vice versa (see Table 6.8). This may indicate that in cases where the VOT difference is large (longer for the plain context) the VD difference is also large (longer for the emphatic context) in order to compensate for the part of the vowel delayed by the voiceless interval.

Table 6.8. Mean VOT, VD and the sum duration of VOT and VD

V	/iː/		/ɪ/		/eː/		/oː/	
C	t	tˤ	t	tˤ	t	tˤ	t	tˤ
VD	106	129	50	56	122	130	142	145
VOT	51	21	35	20	35	17	32	15
sum	157	150	85	76	157	147	174	160
V	/ʊ/		/uː/		/ɛ/		/æː/	
C	t	tˤ	t	tˤ	t	tˤ	t	tˤ
VD	56	64	117	118	65	66	122	129
VOT	35	18	33	19	30	17	30	16
sum	91	82	150	137	95	83	152	145

It should however be noted that the VOT difference between the plain and emphatic consonants is greater than the VD difference. Thus vowel duration alone is not sufficient to account for the temporal relation between VOT and vowel duration. Since closure duration patterns are similar to those of vowel duration in terms of being longer in the emphatic context, this raises the question concerning the relation between the three acoustic parameters of CD, VOT and VD in the plain-emphatic distinction.

The overall distribution of the total duration of CD, VOT and VD is similar for the plain and emphatic contexts (see Figure 6.11). The boxplots show that the median is similar for both contexts. A Mann-Whitney t-test supports these results as the difference between the plain and emphatic contexts is non-significant when the test is run on the total duration of CD, VOT and VD for the emphatic context as compared to the plain one ($z = -.184$, $p > 0.05$). Thus there is an interesting temporal relation between CD, VOT and VD for the /t/-/tˤ/. The total duration of CD, VOT and VD is also similar for the plain and emphatic contexts when each vocalic context is considered separately (see Figure 6.12).

Fig. 6.11. The total duration of CD, VOT and VD for plain and emphatic contexts

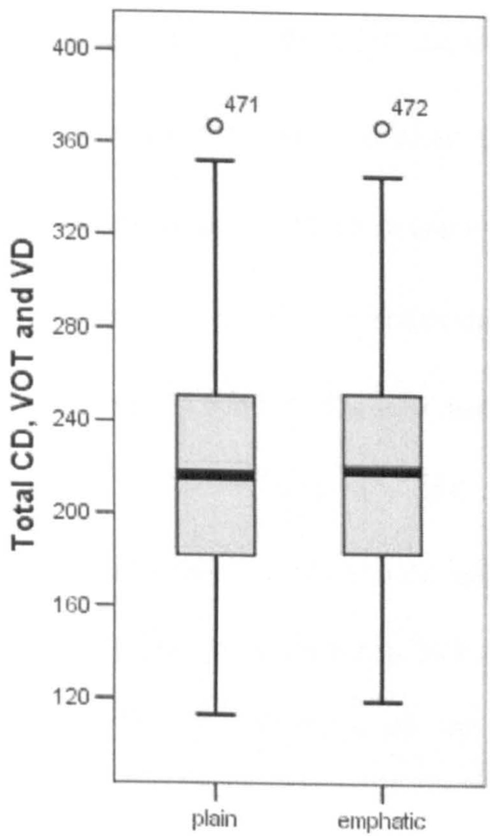
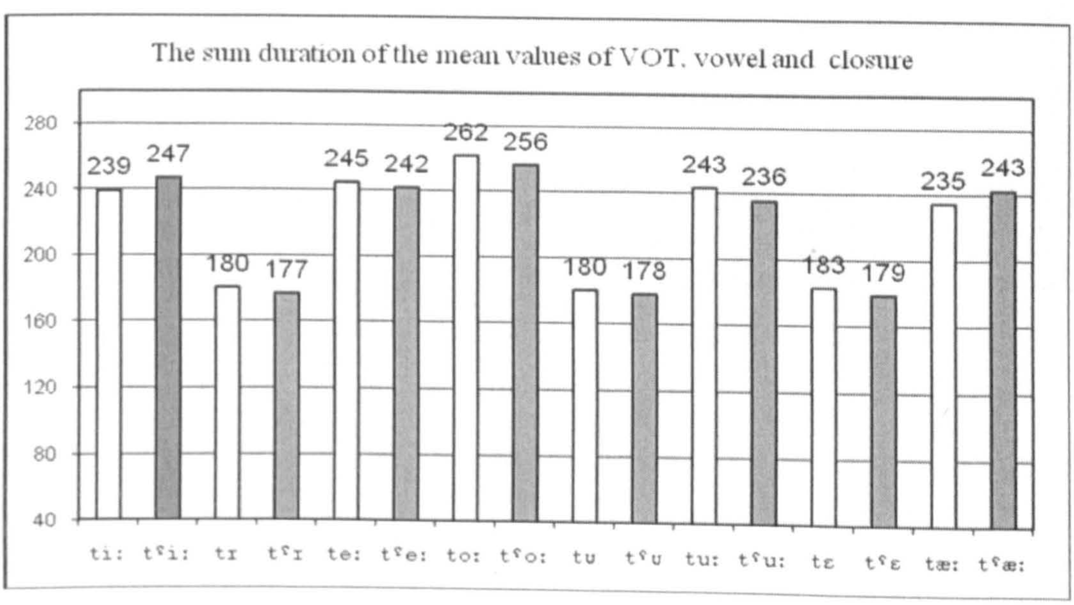


Fig. 6.12. The total duration of CD, VOT and VD for /t/ and /tˤ/ in 8 vowels



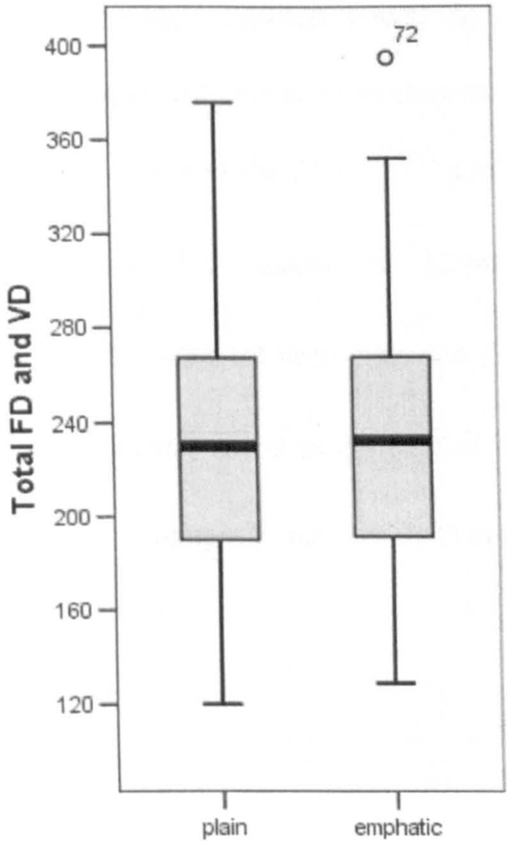
6.7. Acoustic temporal compensation for /s/ and /sˤ/

The temporal relation between CD , VOT and VD in the case of /t/ and /tˤ/ raises the question of whether such a relation also exists for /sˤ/ and /s/ especially since, as reported in this chapter, vowel duration is longer in the context of /sˤ/ than that of /s/ while the fricative duration tends to be longer for the plain than for the emphatic context. The sum duration for the fricative and the following vowel for the context of both /sˤ/ and /s/ is very similar when all vocalic contexts (see Table 6.9). The difference between the two contexts is not significant according to the Mann-Whitney test ($z = -.376$, $p>0.05$). The distribution of data is similar for both the plain and emphatic contexts. The median for two contexts is similar and so is the distribution of 50% of cases (see Figure 6.13). The range for the plain context is wider than that for the emphatic context.

Table 6.9. The sum FD and VD for /sˤ/ and /s/

V	/i:/		/e:/		/o:/		/u/	
C	s	sˤ	s	sˤ	s	sˤ	s	sˤ
FD	139	140	134	127	131	130	128	123
VD	112	121	121	122	124	129	51	56
sum	251	261	255	249	255	259	179	179
V	/u:/		/ɛ/		/æ:/			
C	s	sˤ	s	sˤ	s	sˤ		
FD	125	125	114	113	126	122		
VD	111	118	62	63	132	131		
sum	236	243	176	176	258	253		

Fig. 6.13. The total FD and VD in the plain and emphatic contexts



6.8. Summary of duration and intensity results

In this chapter, emphasis is observed to be influencing some (but not all) acoustic parameters related to duration. For instance, CD and VD are longer for the context of /tˤ/ compared to that of /t/. On the other hand, in all vocalic contexts investigated, /t/ has considerably higher VOT than /tˤ/. There seems to be evidence for a temporal relation between CD, VOT and VD, since the sum of the mean values for these three acoustic parameters is similar in the plain and emphatic contexts.

The overall results show that vowel duration is significantly longer in the emphatic than in the plain context. This significant effect does not seem to be important as the mean difference between the plain and emphatic contexts is small. The significant difference between vowel duration in the plain and emphatic contexts is not consistent across all consonantal types. The significant difference is only reported in case of the /t/-/tˤ/ contrast, but not in the case of the /s/-/sˤ/ and /d/-/dˤ/ oppositions. There is also no significant durational and intensity differences between /s/ and /sˤ/. The total duration of the fricative and the following vowel in the case of /s/ and /sˤ/ tends to suggest that there is also a temporal relation between the fricative and the following vowel.

Chapter Seven

Discussion and Conclusion

7.0. Introduction

This chapter discusses the acoustic results presented in chapters four, five and six in separate sections. Each section starts with a summary of the results reported in the previous chapters. The findings of this study are discussed in light of relevant literature and existing theoretical underpinning. There is a section that brings together results from the acoustic patterns investigated for the implementation of the plain-emphatic contrast in LA. First, the aim of this study and the acoustic parameters investigated in this study are presented briefly.

7.1. Aims of the current investigation

The lack of phonetic studies of Libyan Arabic in general and of acoustic studies of its emphatics in particular has motivated this acoustic and auditory investigation of emphasis. The broad aim of this study is to explore how the secondary articulation of the emphatics in LA is manifest in the acoustic patterns and how the realisation of this articulation distinguishes the patterns of emphasis in LA from other dialects. To achieve this goal, the role of a number of acoustic parameters in the plain-emphatic distinction was investigated. Twenty LA native speakers were asked to produce sentences with word-initial emphatic /tˤ dˤ sˤ/ and their plain counterparts /t d s/ in the syllable structure CVC in which V was one of the Libyan Arabic eight vowels /iː ɪ eː ɛ æː oː uː ʊ/.

Measurements were taken from the first three formant frequencies at the onset and midpoint of the vowel following the emphatic and plain consonants. This was to find out how information about the realisation of the secondary articulation could be inferred from formant frequency patterns and whether the change in formant frequency patterns for the plain and emphatic contexts corresponded to the plain and emphatic allophones of vowels as shown by the auditory analysis.

Furthermore, locus equation parameters were elicited from the regression analysis of F2 onset and F2 midpoint in order to characterise CV coarticulation for the plain and emphatic consonants in Libyan Arabic. The investigation of CV coarticulation was carried out to reveal the role of the secondary articulation in resisting coarticulation with the following vowel given that consonants with such an articulation were found to impose constraints on coarticulation and showed coarticulation resistance to other segments.

The duration of some acoustic parameters in both contexts was also taken; these included closure duration and VOT for /t/ and /tˤ/ in addition to vowel duration in different consonantal contexts. The fricative duration and intensity for /s/ and /sˤ/were measured. As the emphatic consonants are often regarded as tense articulations due to their secondary articulation and are therefore expected to have longer duration than their plain counterparts, this study attempted to investigate the durational and intensity difference between /s/ and /sˤ/ in order to explore the factors that might lead to any durational difference.

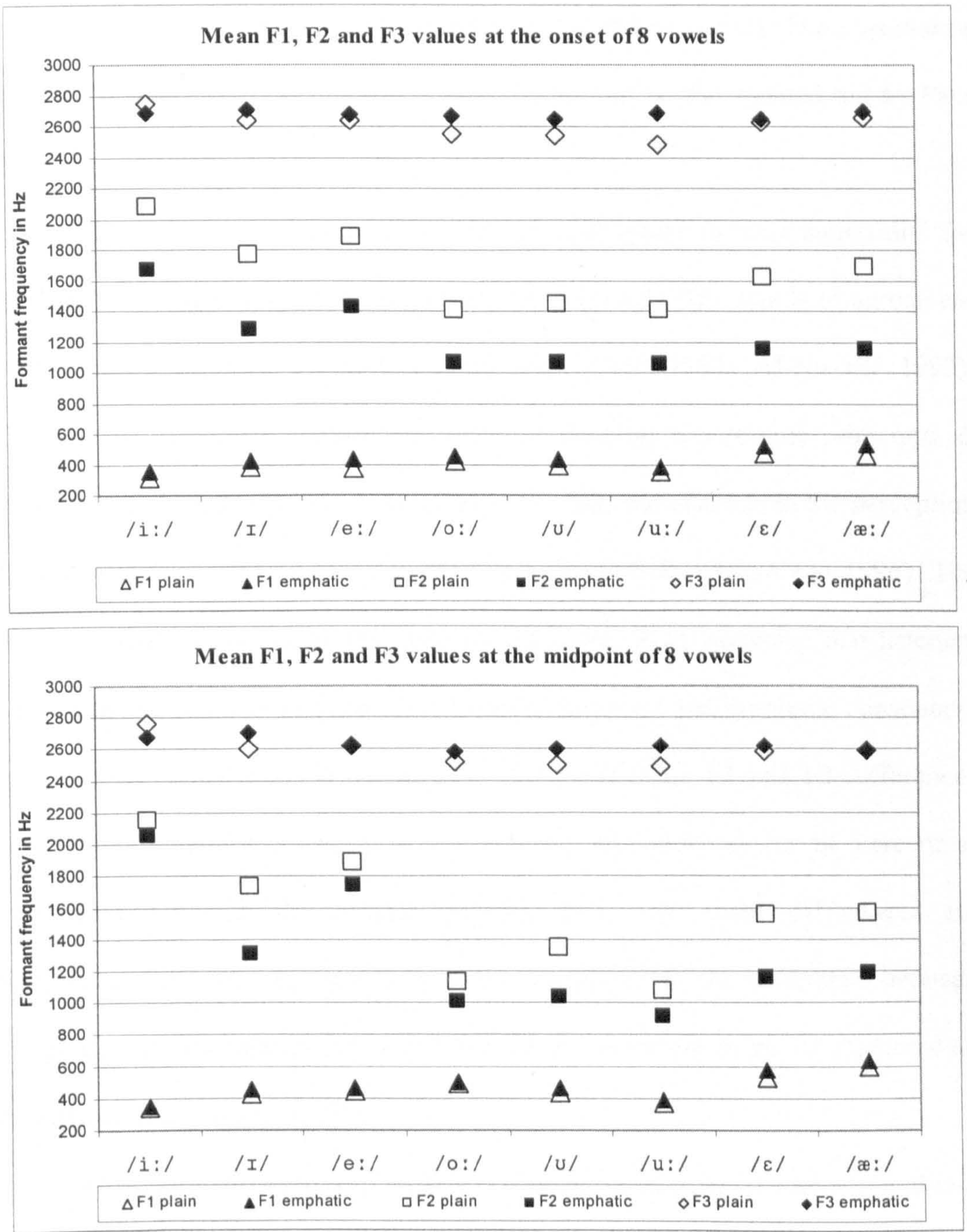
7.2. Discussion of formant frequency results

Results reported in chapter four show that the emphatic consonants affect the first three formant frequencies at vowel onset and midpoint; there is also a change in vowel allophones in the emphatic context. Generally speaking, F1 and F3 increase while F2 decreases in the emphatic environment (see Figure 7.1). This pattern is consistent across all vocalic contexts investigated apart from F3 decrease at the onset and midpoint of /iː/ in the emphatic context. The effect of emphasis is greater at the onset than the midpoint of adjacent vowels, particularly for F1 and F2. This effect could vary depending on vowel quality and duration.

The formant frequency results reported in the current study are more consistent for the first two formant frequencies than for the third one. For F1 and F2, the difference between the plain and emphatic contexts is significant at both the onset and midpoint of all vocalic contexts. The importance of the first two formant frequencies in the plain-emphatic distinction is highlighted by a number of studies (Hussain 1985 in Gulf Arabic; Yeou 2001 in Moroccan Arabic; Kriba 2004 in Libyan Arabic among others). This may be the reason why most studies on emphasis tend to only examine the first two formant frequencies, which determine vowel quality (Peterson 1951; Kent and Read 1992) and serve as adequate acoustic cues for vowel perception (Strange 1989).

The F1 increase and F2 decrease, which are associated with the emphatic context in the current study and other studies on emphasis (see chapter two, section 2.5.1.2.), indicate that emphasis leads to the backing and/or lowering of adjacent vowels. This is because in the context of the emphatic consonant, the tongue backing forms a pharyngeal constriction, leading to F1 increase and this backing, in turn, widens the oral cavity, leading to F2 decrease (Watson 2002). As the tongue moves from a high to a low position F1 increases, and from a front to a back position F2 decreases (Kent and Read 1992).

Fig. 7.1. Mean F1, F2 and F3 in the plain and emphatic contexts



The effect of emphasis on F1 increase and F2 decrease, according to results from this study, is reflected in the F1-F2 distance as both formant frequencies approach each other particularly at the onset of the adjacent vowel. This F1-F2 approximation characterises the emphatic context as being different from the plain one (Odisho 1973; Giannini and Pettorino 1982). The importance of F1-F2 distance in reflecting the feature [retraction] is also pointed out by Fant (1970).

The magnitude of the emphatic-triggered influence is more substantial for F2 than for F1 as results from the current study reveal. This stands in agreement with acoustic findings of other studies (e.g., Card 1983; Al-Nuzaili 1993), emphasising the direct relation between F2 lowering and tongue retraction as referred to by Delattre (1951). Furthermore, the best acoustic cue in the perception of emphasis is offered by F2 (Obrecht 1968; Al-Nuzaili 1993; Yeou 1996). The effect of emphasis on the second formant frequency is so extensive that listeners could utilise it as a cue to distinguish between the plain and emphatic consonants among other tested acoustic parameters. The small mean F1 and F3 differences between the plain and emphatic contexts do not seem to be of perceptual importance although the overall patterns show that these differences are significant. Furthermore, regardless of the magnitude of the difference between the plain and emphatic contexts, F1 and F3 do not seem to be of a perceptual importance if compared to F2.

Generally speaking, the auditory analysis conducted in this study shows that the effect of emphasis leads to more backing than lowering of adjacent vowels (see chapter four, Table 4.1). This could be the reason why Ghazali (1977) states that the backing gesture associated with the production of the emphatics causes both F1 increase and F2 decrease, but F2 decrease is greater than F1 increase. The backing and/or lowering effect of emphasis is also reported in other studies (e.g., Ghazali 1977; Giannini and Pettorino 1982; Hetzron 1997; Card 1983; Hussain 1985; Bukshaisha 1985 among others). It should be noted that most studies which characterise the emphatic allophones of vowels seem to infer the lowering and backing of these vowels from spectrographic analysis of F1 and F2, but not from an auditory analysis of vowels in the emphatic context (e.g., Giannini and Pettorino 1982; Hussain 1985; Bukshaisha; Norlin 1987; among others). All this implies coarticulatory effects in the sense that the tongue keeps the position necessary for the production of the emphatic consonants during vowel production (Laufer and Baer 1988; Hussain 1985; Ali and Daniloff 1972b).

Results from this study show that there is a slight auditory change in the case of the high front long vowels /iː/ and /eː/ (see chapter four, section 4.1). Both vowels are backed in the emphatic context. The effect of emphasis is considerable at their onset, but it is reduced as these vowels approach their midpoint. The considerable effect of emphasis on the onset of adjacent vowels compared to that on their midpoint seems to be the reason why researchers like Card (1983) and Hussain (1985) speculate that /iː/ is not backed in the emphatic environment.

Results from the current study show that high front vowels /iː/ and /eː/ are reported to resist coarticulation with the emphatic gesture as the effect of emphasis is considerable at the onset, but decreases as these vowels reach their midpoint. Such results are also reported in other studies (Ghazali 1977) for some Arabic dialects, Younes (1982) and Card (1983) for Palestinian Arabic and

Bukshaisha (1985) for Qatari Arabic. This effect is particularly manifest in a large rising F2 transition for /iː/ and /eː/ in the emphatic context. This transition reflects the gradual tongue movement from an emphatic consonant to a front vowel position (Ghazali 1977). As the tongue tip or blade moves away from the constriction for the consonant, the secondary gesture remains in place while the vowel is produced, leading to the vowel onset having low F2, which increases as the secondary articulation disappears gradually and the vowel achieves its articulatory configuration (Bukshaisha 1985).

Although /ɪ/ is classified as a high front vowel like /iː/ and /eː/, being short renders it subject to greater influence on the part of emphasis as compared to these long vowels. This effect is particularly considerable on F2 at both the onset and midpoint of /ɪ/ showing that this short vowel, unlike the long /iː/, does not approach its steady state in the emphatic context as confirmed by other studies (e.g., Hussain 1985; Bukshaisha 1985). In fact, in the emphatic context, a short vowel can have a rising F2 transition (Hussain 1985; Bukshaisha 1985), and Bukshaisha (1985) states that for most cases a short vowel displays no F2 transition and F2 is lowered throughout the whole vowel. All this explains the considerable effect of emphasis on the short /ɪ/, confirming that this short vowel does not reach its steady state.

In this study, further evidence for /ɪ/ not reaching its target comes from the auditory analysis, which reveals an auditory impression of a central allophone [ɨ] in the emphatic context. This indicates that the emphatic gesture spreads throughout the whole duration of the short vowel, but this is not true for the long /iː/ (Card 1983; Norlin 1987). The time factor is important in this respect given that for long vowels, the coarticulatory influence can be reduced, but this is not true for short vowels (Norlin 1987). As the long vowel can resist the effect of emphasis which is more extensive on its onset than on its midpoint, it approaches the steady state found in the plain context, while short vowels do not regain the steady state found in the plain context (Hussain 1985; Card 1983; Norlin 1987). This emphasises the relationship between the short duration and the degree of formant undershoot (Lindblom 1963b; Engstrand and Krull 1988, 1989; Strange 1989).

The auditory impression for the back vowels /u: ʊ o:/ in the emphatic context shows that the backing of these vowels is enhanced. This tendency for these back vowels is also reported for Gulf Arabic (Hussain 1985). Generally speaking, the effect of emphasis decreases for back vowels; therefore, the extent of the F2 transition decreases as the vowel moves from front to back. Back vowels like /u:/, /u/ and/or /o:/ exhibit no F2 transition in the emphatic context (Ghazali 1977; Younes 1982; Card 1983; Bukshaisha 1985), suggesting that there is compatibility between the articulation of these back vowels and the emphatic consonant.

Thus results from this study show that the effect of emphasis could be shaped by the quality of adjacent vowels. For instance, it is found that the high front vowels /i:/ and /e:/ are more influenced by emphasis than the back vowels /o: u: ʊ/. This is expected given that the effect of speech sounds on adjacent segments could vary depending on the articulatory configuration difference between adjacent segments; this effect increases as the difference increases (Rosner and Pickering 1994; Recasens 1999; Recasens et al 1998). This is applicable to our results if considering that compatibility between the backing gesture of emphasis and back vowels reduces the effect of emphasis on these vowels and increases coarticulation while incompatible articulation between emphasis and high front vowels increases coarticulation resistance.

The considerable F1 and F2 differences between the plain and emphatic contexts are due to the opposing effects each of the plain and emphatic contexts exert on the adjacent back vowels. For instance, the back vowels /uːu oː/ have a falling transition in the plain context (Bukshaisha 1985). This represents the transitional movement for F2 from a coronal articulation to back vowel articulation.

As for the low short and long vowels, it is possible to notice the auditory difference between plain and emphatic allophones in addition to the change in F1 and F2 patterns at both the onset and the midpoint (see Figure 7.1). Thus the vowels /ɛ/ and /æː/ are realised as [ʌ] and [ɐ̟] respectively in the emphatic environment. There is also a slight overlapping acoustic space between the plain and emphatic contexts for the vowels /ɛ/ and /æː/, particularly along the front-back dimension, suggesting that the plain and emphatic realisations of /ɛ/ and /æː/ are more separated by means of F2 than F1 for almost all speakers. This is because low vowels move across the front-back acoustic space to achieve compatibility with the articulation of the emphatic gesture.

Most studies on emphasis in Arabic confirm the difference between the plain and emphatic allophones in the low vowel context and they often tend to transcribe the plain as [æ(ː)] or [a(ː)] and the emphatic as [ɑ(ː)] (Paddock 1970; Bukshaisha 1985; Ghazali 1977; Yeou 1997; Haddad 1984; Card 1983;

Hussain 1985; Laradi 1983; Abumdas 1985 among others). Both Laradi (1983) and Abumdas (1985) described the plain allophone of the low vowel as [a(:)] and the emphatic one as [ɑ(:)] for Libyan Arabic. In this study the auditory impression shows that in the emphatic context /ɛ/ is realised as[ʌ]; it is not completely backed compared to [ɑ]. The emphatic allophone for the long /æ :/ in this study is also not completely backed and not very low; it tends to be realised as [ɐ̝].

In spite of the allophonic variation across different studies, the low vowel changes from a front vowel in the plain context into a more back vowel in the emphatic context. This tendency is attributed to a similarity between the articulation of both the emphatic consonants and the low vowels as both involve a pharyngeal constriction (Delattre 1971; Al-Ani and El-Dalee 1983; El-Dalee 1984). Laradi's (1983) videofluorographic investigation of LA confirms the similarity of the pharyngeal constriction between /tˤ/ and the low vowel in /tˤa:b/. This also explains why the influence of emphasis extends to the whole vowel duration (Ghazali 1977; Bukshaisha 1985) and the change in F1 and F2 patterns is observed at both the onset and midpoint of these vowels in the emphatic environment (Yeou 1997). As the effect of emphasis is great at the onset and midpoint of the vowel, the auditory impression could clearly separate a plain from an emphatic allophone.

In this study, the general results show that F3 increases in the emphatic context yet F3 remains the least influenced formant frequency by emphasis and the effect tends to vary according to vowel quality. This may be the reason why the role of F3 is played down alongside other factors like inconsistent patterns between the plain and emphatic contexts (Giannini and Pettorino 1982; Al-Ani and El-Dalee 1983; El-Dalee 1984; Norlin 1987; Al-Nuzaili 1993; Khattab et al 2006). Although the mean F3 difference between plain and emphatic contexts is small, the overall results show that it is significant. As discussed in section 7.6, there is evidence for the role of F3 increase in locating the constricted area in the pharynx.

Results from this study agree with Norlin (1987) and Kriba's (2004) studies which suggest that the F3 role in the plain-emphatic distinction is best observed for back vowels, particularly /u:/. The vowel /i:/, unlike other vowels, shows an F3 decrease in the emphatic context. This could be related to the quality of /i:/ which shows great resistance to emphatic articulation and the effect of emphasis is more pronounced at its onset. In fact, F3 for /i:/ could show different patterns cross-dialectally as in Egyptian Arabic (Norlin 1987) and Libyan Arabic (Kriba 2004) F3 decreases in the emphatic context while in Jordanian Arabic (Jongman et al 2007) F3 increases. Thus the tendency of F3 for /i:/ to increase in some, but not all Arabic dialects could be accepted if considering some factors. First, the quality of /i:/ as being tenser in some dialects could lead to cross-dialectal variation as far as the effect of emphasis on F3 is concerned. This is because a tenser vowel may show more resistance to the emphatic coarticulation so the effect of emphasis may not be observed on F3 which is the least affected formant frequency. This could be the reason why in different Arabic dialects the vowel /i:/ shows different patterns under the influence of emphasis. Bukshaisha (1985) reports that the high front vowel /i:/

acquires and allows the spread of the emphatic gesture in Qatari Arabic, but not in other Arabic dialects (see chapter 2, section 2.8 for more details).

Furthermore, the F3 decrease associated with the high front vowel /iː/ in Libyan Arabic may be justified if considering Laradi's (1983) videofluorogaphic results for /tˤ/ in /tˤiːn/. The slight retraction of the tongue is observed as high as the second cervical vertebrae (C2), but the cross-sectional configuration underneath C2 is wide and the front of the tongue is still in a high position. Laradi (1983) also mentions the raising of the tongue towards the soft palate for /tˤ/ in /tˤiːn/. This suggests that the constriction for this vowel in LA is not as low in the posterior part of the vocal tract as shown by Laradi's (1983) general articulatory patterns of emphasis. As discussed in section 7.6, the higher the pharyngeal constriction is, the lower the F3. One may wonder why other high front vowel like /eː/ and /ɪ/ behave differently in terms of showing the increasing effect of emphasis on F3. This could be related to the quality and quantity of these vowels. However, the increasing effect of emphasis on /eː/ is not significant and this vowel is found to resist coarticulation with emphasis in a similar way to the vowel /iː/ as discussed in this section. Yet /eː/ is not as tense as /iː/, and this may be the reason why /eː/ is still slightly affected by emphasis. Tense vowels are generally longer and have stronger articulation than lax vowel; this allows them to resist emphasis spread more than lax vowels. The significant effect of emphasis on F3 for /ɪ/ may be related to the fact that being short renders /ɪ/ subject to great formant undershoot under the influence of emphasis.

The distribution of formant frequency measures at the onset and midpoint displays a great deal of inter-speaker variability for all vocalic contexts examined and for all formant frequencies (see chapter four). This is because speakers could vary the degree of tongue backing for the emphatic consonant and tongue fronting for the plain consonant (Khattab 2006 et al), especially if considering that the production of the emphatic consonants may be controlled by other vocal tract activities that could affect formant frequencies (see discussion at the end of this section). So speakers can employ a range of articulatory strategies and may manipulate these articulatory correlates of emphasis differently, leading to acoustic variation as far as formant frequencies are concerned. Variation could also occur as a result of other factors like the consonantal context, speaking rate, vocal tract size, dialect etc. (Lindblom 1963; Rosner and Pickering 1994; Pisoni and Lively 1995; Ryalls 1996; Frieda et al 2000).

A certain consonant could affect formant frequency patterns in a different way as compared to another consonant. The formant frequency values for each consonantal type show that formant frequency patterns can differ, depending on the consonantal context. For instance, F1 onset in the plain context of /d/ is lower than that in the context of /t/ and /s/ while F2 onset is higher in the /d/ context than in the /t/ and /s/ contexts (see also appendix 2 for formant frequencies in different consonantal and vocalic contexts). This is due to the early start of F1 and F2 for vowels following the voiced /d/. This is attributed to the difference in the relative timing of tongue movements from the position for the consonant to that of the vowel (Fant 1973). These movements are said to occur earlier in the context of a voiced consonant as opposed to that of the voiceless ones as also confirmed by Gay's (1979) EMG data. This leads to the early start of vowel formant frequencies in the context of a voiced consonant, subjecting the formant frequencies to great effect on the part of the preceding voiced consonant.

Generally speaking, results from this study show that the context of /sˤ/ is associated with the highest F2 onset. This effect is particularly evident for the vowel /iː/, F2 onset lowering in the emphatic context of /sˤ/ is less extensive than in the emphatic contexts of /dˤ/ and /tˤ/ (see means in appendix 2). Similar results are reported by Bin-Muqbil (2006) for MSA given that F2 for /sˤ/ is significantly higher than that for the other emphatics. Explanation for this may come from articulatory studies (e.g., Ghazali 1977; Laufer 1988) in which the secondary articulation for /sˤ/ has a wider constriction than that for /tˤ/. In fact, Laufer and Baer's (1988) articulatory study shows that the degree of the pharyngeal constriction for the emphatic consonants could also depend on the vowel as they report a wider constriction for /i/ than for /a/.

In this study, there is inter-speaker variability in the production of emphasis as reflected in formant frequency patterns. The extent of this variability is not directly reflected in the auditory impression of vowel allophones, as the phonetic transcription is kept generally broad. Moreover, even a fine-grained narrow transcription would not necessarily reveal the inherent acoustic variability that is present in the signal. As will be discussed later in this section, it is possible to have acoustic variability in the realisation of one vowel yet listeners can identify the category of the vowel.

The discrepancy between auditory and acoustic analyses observed in this study may also be explained by the theory of "perceptual magnet" (Kuhl 1991;

Kuhl et al 1992; Kuhl 2000) in which the prototype of a vowel category is utilised as a perceptual magnet that draws other similar members of the category which are difficult to distinguish, but not those different members that belong to other categories. This reflects the ability of listeners to determine the category of a vowel in spite of the acoustic variability. Another explanation of how listeners could process a large set of acoustic events as the same auditory event comes from Lindblom's (1990, 1996) H and H theory although this theory is applied to daily interaction rather than to data used for an experimental investigation. Yet it shows the ability of speakers to vary their articulation on a continuum of hyper- and hypo-articulation and how listeners concentrate on the message and the meaning of the target word that they are being presented with, thereby applying top-down processes to the listening task and overlooking certain acoustic differences.

As the emphatic consonants are associated with a number of articulatory correlates that yield different acoustic results, the results from this study in relation to the effect of emphasis on F1 and F3 increase and F2 decrease can support some, but not all the correlates of emphasis. These results are explained in the light of the effect of the pharyngeal constriction on formant frequencies. However these results can either be enhanced or counteracted by some articulatory correlates of emphasis given that the articulatory correlates of emphasis are too complex to be described by a single articulatory feature (Al-Nuzaili 1993). For instance, larynx raising, which may be one of the correlates of emphasis (Laradi 1983), increases the first three frequencies as a function of reducing the vocal tract length while lip rounding decreases all frequencies (Stevens 2000). Lip rounding and/or lip protrusion also correlates with emphasis (Lehn 1968). The retraction of the primary articulation may also decrease the vocal tract size and lower all formant frequencies, although Ghazali (1977) plays down its acoustic effect. In analysing formant frequency results from this study, one should take into consideration that the emphatic consonants have other articulatory correlates that could act together with the pharyngeal constriction to shape the final acoustic output.

7.3. Discussion of locus equation results

The formant frequency results reveal that F2 movement patterns from the onset to the midpoint of the vowel following the plain and emphatic consonants provide CV coarticulatory information. The coarticulatory pattern is affected by how each of these consonant classes coarticulates with the adjacent vowel (see chapter four, section 4.5 for details on formant frequency changing patterns for the plain and emphatic contexts). The results observed in this study suggest that coarticulation depends on the articulatory difference between the adjacent segments which are involved in the coarticulatory process as referred to by Rosner and Pickering (1994), Recasens (1999) and Recasens et al (1998). F2 patterns also show how CV coarticulation is influenced by variation in formant frequencies as a function of speaker and consonantal type, and this is supported by LE results. LE parameters further provide a comprehensive and objective way of encoding CV coarticulation through the regression analysis of F2 at vowel onset and midpoint as indicated by Lindblom (1963a); therefore, coarticulatory information could be inferred from F2 movement patterns (Delattre 1951; Liberman et al 1967; Al-Nuzaili 1993). It is also consistently found that the most influenced formant frequency by emphasis is F2 as reported in this study (see chapter four) and in other Arabic dialects (see discussion in the previous section).

General results for the LE slope from the current study show that the emphatic consonants exhibit a flatter (lower) slope than their plain counterparts (see Table 7.1). Such results suggest that the emphatic consonants resist coarticulation with the following vowel more than the plain consonants given that flat slopes indicate that CV coarticulation decreases and there is CV coarticulatory effects (Krull 1987, 1988, 1989).

Table 7.1. Mean LE parameters for plain and emphatic consonants

C	/t/	/tˤ/	/s/	/sˤ/	/d/	/dˤ/	plain	emphatic
slope	0.71	0.56	0.68	0.63	0.47	0.46	0.63	0.55
y-intercept	588	466	578	443	963	644	684	515

These results are also predicted by the coarticulation resistance model (Bladon and Al-Bamerni 1976) and the degrees of articulatory constraint model (Recasens 1984a, 1984b, 1985, 1987, 1991, 1999; Recasens et al 1995, 1996, 1997, 1998). The relevance of such models to results from the current study lies in the explanation provided for the relation between the degree of coarticulation resistance and the extent of articulatory constraint since resistance is found to vary with the consonant's demand on the articulators concerned. In this case, the articulatory constraint model (Recasens et al 1997) shows that the velarised [lˠ] exhibits a lesser degree of coarticulation than other segments which have only one primary articulation due to a larger degree of articulatory control imposed on the tongue in the production of [lˠ] which has velarisation as a secondary articulation. Similar observation is reported for the emphatic consonants which impose a high requirement on the tongue body due to the presence of the secondary articulation which distinguish them from their plain counterparts. Thus, the coarticulatory effects in a CV syllable is greater for the emphatic consonants than for their plain counterparts in LA (this study) as also reported in MSA and other Arabic dialects (Sussman et al 1993; Yeou 1997; Embarki 2006; Embarki et al 2007).

Although the general results in the current study show that the LE slope could distinguish the plain from the emphatic consonant and therefore signal the effect of the secondary articulation of the emphatics on coarticulation, some factors are found to influence the degree of coarticulation such as speaker, consonantal type and dialect.

The slope results do not exhibit a consistent pattern across different speakers. For the majority of speakers, the emphatic context has a flatter slope than the plain context while contrary results are reported for some speakers (see chapter five, section 5.2). All this suggests that the degree of CV coarticulation could depend on the speaker. This speaker variability does not affect the realisation of the emphatic consonant. In Egyptian Arabic the slope for the emphatic context is higher than that for the emphatic context for one of three speakers in Sussman et al's (1993) study.

Furthermore, as the LE slope is higher in the emphatic context than the plain context for some speakers, this may be expected if taking into consideration that the result for each speaker is calculated for nine tokens, eight vowels and three consonantal types. This involves an overall description of CV coarticulation. Coarticulation is affected by certain factors (e.g., vowel quality, consonantal type and speaker). These factors play a role to produce the final output. As the emphatics resist coarticulation with some vowels, the plain consonants do also resist coarticulation with some others and vice versa. Due to the secondary articulation the emphatics presumably show more resistance to coarticulation with adjacent vowels, and this expected tendency is shown in the overall results in this study. Exceptions do exist even for certain dialects, not just for speakers. As will be discussed later, overall results from Moroccan Arabic show that the emphatic consonants have higher slope than their plain counterparts.

It is observed that contextual differences could influence the degree of CV coarticulation when LE slope results from this study are computed for each consonantal type. In fact, the voiced /dˤ/ is distinguished from the voiceless /tˤ/ and /sˤ/ and the plain /d/ from /t/ and /s/ by means of both their slope and y-intercept. It is also reported that in LA (this study) and other Arabic dialects and varieties (see appendix 7b) the slope order shows that the voiceless consonants have higher slope than their voiced counterparts. This is consistent for both the plain and emphatic contexts. The voiced consonants have flatter slopes than the voiceless ones, suggesting more CV coarticulation resistance for the voiced rather than for the voiceless consonants. Support for such results comes from some studies given that the voiced consonants tend to have a lesser degree of coarticulation with the adjacent segments than the voiceless consonants (Gay 1979; Engstrand 1989; Farnetani 1990; Yeou 1997; Engstrand and Lindblom 1997; Modarresi et al 2004). This is because vowel formant frequencies start earlier in the case of the voice consonants than in the case of the voiceless ones and therefore they are subject to greater effect on the part of the voiced consonant. Furthermore, the role of LE in distinguishing consonants with the same place of articulation, but with different manners of articulation and different voicing states is questioned by Fowler (1994). This could be one of the reasons why locus equation is not capable of grouping together the emphatic consonants of difference voicing states as well as their plain counterparts. In fact, locus equation is first used to signal the consonantal place of articulation for voiced stops and has been found to be efficient in doing so (Lindblom 1963a; Nearey and Shammass 1987; Sussman et al 1991).

As presented in Table 7.2, some studies on the LE slope focus on voiced consonants, showing that the slope values reported for /d/ in most studies are similar to that reported for the Libyan Arabic /d/ at (0.47). These studies adopted the same measuring point as the current study for quantifying LE parameters (F2 is measured at the onset and midpoint). This similarity between the /d/ slope in LA and in other languages and dialects seems to be indicative of the similar degrees of CV coarticulation.

Table 7.2. Slope values for /d/ in different studies

dialect	researcher	/d/
Swedish	Lindblom (1963a)	0.28
Canadian English	Nearey and Shammas (1987)	0.50
American English	Sussman et al (1993)	0.42
American English	Fowler (1994)	0.47
American English	Sussman and Shore (1997)	0.40
AE and Persian	Modarresi et al (2005)	0.43

The other factor that is found to influence coarticulation is the dialect. Although the results observed in this study and other Arabic dialects (Sussman et al 1993; Yeou 1997; Embarki 2006; Embarki et al 2007) show that the emphatic context is associated with a flatter slope, in some dialects like Moroccan Arabic (Embarki et al 2007), for instance, the slope is flatter for the plain than for the emphatic context. Thus in Moroccan Arabic, the secondary articulation associated with the emphatic articulation does not support the predictions of the coarticulation resistance model (Bladon and Al-Bamerni 1976; Recasens et al 1997). However, as Bladon and Al-Bamerni (1976) note that coarticulation resistance should not be viewed as a universal principle, results from Moroccan Arabic could be accepted as part of cross-dialectal variation. Coarticulation is therefore mentally represented and not only restricted to the effect of segments on one another (Daniloff and Hammarberg 1973; Hammarberg 1976). Dialectal variation is observed in the flatter slopes for the emphatics in the eastern than in the western dialects of Arabic and as speakers switch from MSA to their native dialect, LE slope is lowered for the pharyngealised, but not for the non-pharyngealised consonants (Embarki et al 2007). This reveals that the variety-specific articulatory patterns, resulting from mental representations, can not be transferred from Arabic dialects to MSA (Embarki et al 2007). The same speakers can implement the MSA articulatory pattern representing the formal style of MSA and switch to dialect-specific articulatory features.

The LE slope results show that Moroccan Arabic (MA) is different from Libyan Arabic (LA) in terms of having flatter slopes for the plain than for the emphatic consonants. Both LA and MA are classified as western Arabic dialects (Versteegh 1997; Watson 2002), but they show different patterns. This is because dialectal variation may also exist between countries, cities and regions (Mitchell 1962; Mansouri 2000). Furthermore, only four speakers are used for the study of MA. Therefore if the number of speakers from larger, the representation will be better.

LA Arabic exhibits some similar results to those of other dialects. For instance, the slope difference between /t/ and /tˤ/ is great in LA (this study) and in MA, JA, YA and KA (see appendix 7a) as well as in MSA (Yeou 1997; Embarki et al 2007). In LA, slight and non-significant slope difference could not distinguish between /d/ and /dˤ/ as compared with other Arabic dialects and MSA (see appendix 7a), but the y-intercept difference is significant for this voiced contrast in LA (this study). Similar results are reported by Sussman et al (1993) in Egyptian Arabic for /d/ and /dˤ/ slope and y-intercept. Thus in LA and Egyptian Arabic, the /d/-/dˤ/ contrast seems to have dialect-specific coarticulatory features. In this case, a lower y-intercept in the emphatic context reflects a low F2 onset and thus the presence of the secondary articulation of the emphatics for both dialects (Sussman et al 1993).

The slight slope difference between /s/ and /sˤ/ in the current study is also observed in JA, MA and in MSA in Embarki et al's (2007) study (0.047), but not in KA, YA and MSA in Yeou's (1997) study (see appendix 7a). So LA is similar to some Arabic dialects, and different from other dialects in which the /s/-/sˤ/ contrast can be better distinguished by slope values. Yet, the LA emphatic /sˤ/ is still distinguished from its plain counterpart /s/ by means of its y-intercept values.

When coarticulation varies cross-dialectally as the results discussed earlier in this section show, other factors related to the range of consonant and vowel inventories in a language could play a role in this cross-dialectal variation (Lindblom 1990; Manuel 1990; Beddor et al 2002; Gick et al 2006). For instance, this study on LA uses three coronal plain consonants and their emphatic counterparts followed by eight vowels of different qualities (see chapter 3). In their investigation of Jordanian, Kuwaiti, Moroccan and Yemeni Arabic, Embarki et al (2007) use the pharyngealised consonants /tˤ dˤ sˤ ðˤ/ and their non-pharyngealised counterparts /t d s ð/ followed by the vowels /i u a/. As the degree of CV coarticulation depends on the compatibility between the consonant and the following vowel, this might partly explain the differences in results between the two studies. As reported in chapter 4, section 2.5.1.2 the effect of emphasis on format frequencies depends on vowel quality and quantity.

Results from this study show that y-intercept is found to be lower for the emphatic than for the plain context. The y-intercept results do not provide coarticulatory information like the LE slope, which is often employed as an acoustic measure of CV coarticulation (Krull 1987, 1988, 1989). Therefore, there is more focus on the slope than on the y-intercept given that the main purpose of using LE parameters is to get information about the effect of emphasis on CV coarticulation. The y-intercept results are still important in the sense that the low y-intercept for the emphatic environment can be suggestive of a lower F2 onset due to the presence of the secondary articulation (Sussman et al 1993).

In LA, the mean y-intercept values for the plain consonants /t/, /d/ and /s/ are distinctly and higher than those observed for their emphatic counterparts /tˤ/, /dˤ/ and /sˤ/, particularly the y-intercept between the /d/-/dˤ/ contrast (see appendix 7a). These y-intercept results are observed for all Arabic dialects and varieties surveyed in this study with some exceptions, in which the emphatic context can have higher y-intercepts than the plain one (see appendix 7). These exceptions include KA, YA and MSA produced by

Moroccans (Embarki et al 2007) in which the emphatic /sˤ/ has higher y-intercept than its plain counterpart. The distinctly lower y-intercept for /tˤ/ as compared with /t/ in LA is also reported for the four Arabic dialects (JA, KA, MA and YA) in Embarki et al's (2007) study. Moreover, the lower y-intercept value for the emphatic /tˤ/ compared to the plain /t/ is detected in MSA produced by Kuwaiti speakers, but not in MSA produced by Jordanians, Moroccans, and Yemeni speakers in which y-intercept is considerably higher for the emphatic /tˤ/ than the plain /t/ (Embarki et al 2007) and in MSA produced by Moroccans in Yeou's (1997) study (see appendix 7a).

LA displays a considerably higher y-intercept difference between /d/ (963 Hz) and /dˤ/ (644 Hz), but according to Embarki et al (2007), the difference is even higher in Moroccan Arabic (1010 Hz and 542 Hz for /d/ and /dˤ/ respectively). This y-intercept difference gets smaller for Kuwait and Yemeni and Jordanian Arabic and in MSA (see appendix 7a). It should be noted that Jordanian speakers, unlike LA and other Arabic speakers, show higher y-intercept for the emphatic /dˤ/ than that reported for /d/ both when producing JA and MSA.

This section has shown that the emphatic consonants resist coarticulation with the adjacent vowels more than the plain consonants. This true for most Arabic dialects although the degree of resistance could vary cross-dialectally. CV coarticulation could also vary as a function of speaker and consonantal type. The general pattern for y-intercept indicates a lower y-intercept for the emphatic than for the plain consonants.

7.4. Discussion of duration and intensity results

Emphasis could affect a number of acoustic parameters related to duration. In the emphatic context, these acoustic parameters show different patterns. For instance, CD is found to be longer for the emphatic /tˤ/ than the plain /t/ while VOT is shorter for /tˤ/ than for /t/. The duration and intensity differences between /sˤ/ and /s/ are insignificant. The overall results show that vowel duration is significantly longer in the emphatic than in the plain context in spite of the small mean difference between the two contexts. This significant VD difference is only observed in the case of the /t/-/tˤ/ contrast, but not in the case of the /s/-/sˤ/ and /d/-/dˤ/ contrasts. There is also a temporal relation between closure duration, voice onset time and vowel duration for /t/ and /tˤ/ and between fricative duration and vowel duration for /s/ and /sˤ/.

As reported above in this section and in chapter six, for most acoustic parameters related to duration, the durational difference between the plain and emphatic contexts is not significant, and even when it is significant, the overall mean difference does not seem to be of high importance. Therefore, generally speaking, the duration patterns reported in this study do not reflect the assumptions in the literature, which regard the emphatic consonants as tense articulations, and have therefore longer duration than their plain counterparts (Ali and Daniloff 1972a; Bukshaisha 1985; Al-Bannai 2000). These assumptions as based on the articulation of the emphatic consonants being tense requires exerting great articulatory efforts that lie in tongue retraction, depression of the tongue body and tension in the pharynx (Ali and Daniloff 1972a). This lays the phonetic basis for tense articulations in which considerable muscular tension in the vocal tract requires extra articulatory efforts, leading to long duration (Chomsky and Halle 1968).

In the current study, one of the acoustic parameters that reflect the tendency of the emphatic context to have longer closure duration than the plain context is the closure duration difference between /t/ and /tˤ/. Although this difference is significant, the mean difference is small and may not be of a perceptual importance (mean CD for /t/= 88 ms and for /tˤ/=98 ms). In fact, /tˤ/ has longer closure duration than /t/ in Gulf Arabic (Bukshaisha 1985) and Yemeni Arabic (Al-Nuzaili 1993). Bukshaisha (1985) attributes this to the tense articulation of the emphatic consonants as discussed earlier in this section.

The most important acoustic parameter that suggests the effect of emphasis on duration is VOT. This study shows that VOT is capable of differentiating between /t/ and /tˤ/ in Libyan Arabic with the emphatic /tˤ/ showing shorter VOT than the plain /t/. The same results are reported for most Arabic dialect (see appendix 8). Some of these dialects are very similar to LA in terms of showing a slightly aspirated /t/ and an unaspirated /tˤ/ (e.g., Tunisian Arabic (Ghazali 1977), Jordanian Arabic (Khattab et al 2006), and Iraqi Arabic (Heselwood 1996; Giannini and Pettorino 1982; Odisho 1973). In Moroccan Arabic (Zeroual 1999), Qatari Arabic (Bukshaisha 1985) and Yemeni Arabic (Al-Nuzaili 1993), the emphatic /tˤ/ remains unaspirated whereas the plain /t/ can have relatively strong aspiration.

In some Arabic dialects, the VOT pattern can deviate from that observed for Libyan Arabic (this study) and other Arabic dialects. For instance, in Egyptian Arabic, the VOT difference between /tˤ/ and /t/ is non-significant and both are produced with slight aspiration (Heselwood 1996; Shaheen 1979; Rifaat 2003). The emphatic context still exhibits a slightly shorter VOT than the plain context. In Sudanese Arabic, the emphatic /tˤ/ has unexpectedly longer VOT than the plain /t/ (see appendix 8). One factor that may be relevant here is the number of speakers as for Sudanese Arabic only two male speakers were used in Ahmed's (1984) study and this may not provide a good representation of the dialect.

Results from a study on Libyan Arabic by Kriba (2004), on the other hand, show that both /t/ (VOT = 44 ms) and /tˤ/ (VOT = 33 ms) are aspirated with /t/ having relatively stronger aspiration than /tˤ/. This puts both /t/ and /tˤ/ in the long lag region as determined by Keating (1984) and Laver (1994) whereas in the current study a VOT of 35 ms for /t/ and 18 ms for /tˤ/ keeps the former in the long lag category and the latter in the short lag category. Such varying results between the two studies could be triggered by methodological factors related to the number of speakers and vocalic contexts used. This study uses twenty speakers and eight vocalic contexts while Kriba's (2004) study uses one speaker and three vocalic contexts. This would lead to the current study being more representative of LA than Kriba's (2004) study and accordingly it tackles the issue of the effect of emphasis on VOT more objectively.

The vocalic context may also affect VOT results given that VOT is found to be longer before high vowels than before mid or low vowels (Klatt 1975; Docherty 1992). In this study this effect is better observed for the plain /t/ in the context of /i:/, but not in that of /u:/ which shows a similar pattern to low vowels rather than high vowels. Similar VOT results are reported for Yemeni Arabic (Al-Nuzaili 1993) and for LA in Kriba's (2004) study while the effect of the vocalic context is observed in both the plain and emphatic context in Lebanese Arabic as longer lags are associated with the production of plosives before /i/ than before /a/ or /u/ (Yeni-Komshian et al 1977).

The general pattern observed for Libyan Arabic (this study) and most Arabic dialects discussed in this chapter tends to lend credence to the shortening effect of emphasis on VOT. This influence is attributed to a narrow glottal opening for /tˤ/ as a function of the secondary articulation. The narrowing of the glottis observed in the production of /tˤ/ is caused by the pharyngeal constriction which is accompanied by laryngeal activities that control the state of the glottis and surrounding tissues and lead to the narrowing of the glottis (Esling 1996, 1999, 2005; Esling and Harris 2003). These activities include the narrowing of the aryepiglotic sphincter (Esling 1996) and the approximation of the cuneiform cartilages towards the epiglottis base, (Esling 1999), and the ventricular folds are brought together (Esling and Harris 2003). This explains the reason why the emphatic consonants exhibit lower VOT than their plain counterparts.

Furthermore, fiberscopic studies show that the pharyngealized /tˤ/ has narrower glottal opening than the non-pharyngealized /t/ (El-Halees 1989;

Zeroual 1999). This leads to an aspirated /t/ (VOT= 63 ms) and an unaspirated /tˤ/ (VOT= 24 ms) in Zeroual's (1999) study, reflecting a direct correlation between aspiration and the degree of glottal opening (Kim 1970; Sawashima and Miyazaki 1973; Kagaya 1974; Pétursson 1976; Hutters 1985). However, this does not account for the VOT results reported for Egyptian and Sudanese dialects in which the VOT pattern is not similar to that reported for LA (this study) and other Arabic dialects as discussed earlier in this section. There is also variation in the VOT results across different Arabic dialects as discussed earlier in this section.

This cross-dialectal variation may be attributed to the timing between the stop release and the peak glottal opening (Kim 1970; Hutters 1985; Löfqvist 1980, 1992). For instance, Ridouane (2003) found that both singleton and geminate stops in Berber are aspirated, yet geminates show larger glottal opening than singletons. What matters in this case is the degree of glottal opening at the oral release which is found to be similar for singleton and geminate stops, suggesting that aspiration occurs as a function of the size of glottal opening at the stop release (Kim 1970). Therefore, a cross-dialectal investigation of VOT and the degree of glottal opening at the stop release may be needed in order to account for the cross-dialectal variation in VOT for /tˤ/ and /t/ in the Arabic dialects.

As inter- and intra-speaker variation is reported for this study and this leads to an overlap between the VOT values for /tˤ/ and /t/; such an overlap is observed in other Arabic dialects like Yemeni Arabic (Al-Nuzaili 1993) and Lebanese Arabic (Yeni-Komshian et al 1977). This overlap could also indicate that the degree of glottal opening in the production of both stops could vary across and within speakers. Some studies use a limited number of speakers and this may not represent the dialect. For instance, Al-Nuzaili (1993) presents himself as the only subject in his investigation of VOT. In the current study, 20 speakers are involved.

Results from this study show that as VOT decreases, closure duration increases for /tˤ/ compared to /t/. This could suggest a temporal relationship between VOT and closure duration. In fact, the inverse relationship between VOT and closure duration is documented by Weismer (1980).

Results from the current study concerning the slight and non-significant durational difference between /s/ and /sˤ/ tend to agree with those from some Arabic studies (Iraqi Arabic by Hassan 1981; Gulf Arabic by Hussain 1985; different Arabic dialects by Al-Bannai 2000). On the other hand, /sˤ/ is found to have longer duration than /s/ in Qatari Arabic (Bukshaisha 1985) and standard Jordanian Arabic (Kuriyagawa et al 1988). Therefore, the durational pattern for this contrast is not consistent cross-dialectally. The lack of consistency is also confirmed by Giannini and Pettorino (1982) across different vocalic contexts in Iraqi Arabic: in the opposition /sa:ra/ and /sˤa:ra/, /sˤ/ is longer than /s/ whereas in /si:n/ and /sˤi:n/, /s/ is longer than /sˤ/.

The non-significant duration difference between /s/ and /sˤ/ reported in this study along with the inconsistent durational pattern for this contrast cross-dialectally seems to indicate that the additional articulatory movement required for the production of the emphatic consonant is not acoustically manifested in the longer duration for the emphatic fricative. Bukshaisha (1985) argues for the longer duration for /sˤ/ than /s/ being caused by the tense articulation of /sˤ/. However, results from the current study show no intensity difference between /s/ and /sˤ/.

The overall results observed in this study show that the vowel in the emphatic context is significantly longer than the vowel in the plain context. However, as the mean vowel duration difference between the two contexts is only 5 ms, this difference does not seem to be perceptually important especially if considering that most studies conducted on Arabic dialects show that the vowel duration difference between the plain and emphatic contexts is not significant, e.g., Iraqi Arabic (Ali and Daniloff 1972b), Egyptian Arabic (El-Dalee 1984; Norlin 1987), Gulf Arabic (Hussain 1985) and various Arabic dialects (Al-Bannai 2000). Furthermore, the significant difference between the vowel in the plain context and that in the emphatic context is reported only for the /t/-/tˤ/ contrast, but not for the /s/-/sˤ/ and /d/-/dˤ/ contrasts.

Thus vowel duration may be capable of distinguishing the emphatic context from the plain context only in certain consonantal contexts, namely /t/ and /tˤ/ although the mean vowel duration difference is still small (VD is 106 ms and 98 ms for /tˤ/ and /t/ respectively). Similarly, vowel duration tends to be longer in the emphatic context only in the case of the /t/-/tˤ/ contrast in Gulf Arabic (Hussain 1985). According to Hussain (1985), this is caused by the absence of aspiration in /tˤ/ compared to /t/. This aspiration is manifested as a longer period of voiceless onset of the vowel following /t/. Therefore, the longer VOT for /t/ clearly delays the onset of the following vowel by occupying part of the vowel, and this could cause the VD difference to be of a perceptual significance, at least for some scores, especially when /t/ tends to have strong aspiration (VOT reaches 90 ms) and the /tˤ/ VOT is so short that it coincides with the stop release and it is zero. If lack of aspiration causes vowel duration to be longer for /tˤ/ than /t/, this suggests the presence of a temporal acoustic relationship between VOT and VD as discussed later in this section.

Results from this study indicate that CD, VOT and VD are involved in a temporal relationship; as CD and VD increase for /tˤ/, VOT decreases. Therefore, the total duration of CD, VOT and VD is similar and non-significant for the contexts of /t/ and /tˤ/. A similar relationship is observed for the duration of the emphatic fricative and the following vowel when compared to that of the plain fricative and the following vowel; the total CV duration difference is not significant. It is observed that /sˤ/ has shorter duration than /s/ although the difference is not significant, while the vowel duration tends to be longer in the /sˤ/ than in the /s/ context. Hassan (1981) reports similar results for the duration of /s/ and /sˤ/ and the vowel in their context.

The temporal relationship between the plain and emphatic contexts reported for the /tˤ/-/t/ and /s/-/sˤ/ contrasts indicates that in a CV syllable, the total consonant-vowel duration is similar for both emphatic and plain consonants as predicted by the force of articulation theory (Belasco 1953) and the energy expenditure theory (Lindblom 1968). These theories suggest that the duration for each CV syllabic unit is relatively fixed as both consonant and vowel are involved in a temporal relationship (Machac and Skarnitzl 2007).

This section has shown that in this study only some durational parameters lead to distinguishing the emphatic from its non-emphatic counterpart. The most important parameter is VOT for the /tˤ/-/t/ contrast. Other cues like closure duration can distinguish /tˤ/ from /t/, but they are not as important as VOT. Fricative duration and intensity differences between /s/ and /sˤ/ are not significant. The vowel duration difference between the plain and emphatic contexts, although significant, it is small and does not show a consistent pattern across different consonantal types. There is also a temporal relationship between plain and emphatic contexts in the case of the /tˤ/-/t/ and /s/ and /sˤ/ contrasts.

The following section will bring together the results reported in this study in order to assess their role in reflecting the pattern of emphasis in Libyan Arabic. This is to show which of the acoustic parameters are relevant to the plain-emphatic distinction.

7.5. The articulatory representation of emphasis in LA

This section assesses the role of the acoustic parameters of emphasis in LA in pointing towards emphasis in general and its realisation in particular. Although this study is concerned with acoustic rather than articulatory aspects, the acoustic manifestation of emphasis is taken to be the result of articulatory events and is therefore helpful in estimating the articulation of segments.

The first three formant frequencies are found to be relevant cues to the plain-emphatic distinction in LA with F2 being the most important cue followed by F1 and F3 respectively. These results, as will be discussed in this section, are helpful in suggesting the presence of the secondary articulation and possibly its location in the posterior part of the vocal tract. The most important acoustic cue that is found to be related to locating the secondary articulation in this study is the significant F1 increase in the emphatic context as compared to the plain context; this increase is consistent across all vocalic contexts. The relation between F1 increase and low location of the constricted area in the pharynx is predicted by studies on vocal tract modelling (Malmberg 1963; Klatt and Stevens 1969; Lindblom and Sundberg 1971; Norlin 1987; Yeou 2001). Further evidence for the pharyngealisation of the LA emphatic consonants comes from Laradi's (1983) articulatory study of emphasis in the Libyan dialect spoken in Tripoli, the capital city of Libya, whereby the emphatic consonants investigated are found to have a constriction in the lower pharynx. In such a case there seems to be a correspondence between the acoustic results of Zliten Libyan Arabic (ZLA) (this study) and the articulatory results of Tripoli Libyan Arabic (TLA) (Laradi 1983), particularly if taking into account that both dialects are included within the same Tripolitanian dialectal region, part of the western dialectal area in Libya.

Articulatory-acoustic correspondence between F1 and the realisation of the secondary articulation is also reported for Iraqi Arabic (Pettorino and Giannini 1982). In this case, the lateral consonant is velarised and has the same F1 locus as its non-velarised counterpart, while other coronal emphatic consonants are pharyngealised and exhibit higher F1 locus than the plain coronal consonants. Bin-Muqbil (2006) also treats the emphatic consonants in MSA as velarised since they display no acoustic effect on F1.

If F3 increase occurs as the posterior constriction moves to the lower pharyngeal area (Lindblom and Sundberg 1971; Kent and Read 1992; Stevens 2000; Yeou 2001), then results from this study could add further acoustic evidence for the emphatics being produced with a pharyngeal constriction rather than a velar or uvular one. The overall results are helpful in predicting this and so are results for most vocalic contexts. In fact, the effect of emphasis on F1 is more consistent than on F3 as it is consistent across all vocalic contexts (see chapter four). This could indicate that F1 may be more important than F3 in providing information about the secondary articulation.

The role of F2 decrease does not seem to be very relevant to locating the secondary articulation of the emphatic consonants although it indicates the presence of the secondary articulation regardless of whether it is velarisation, uvularisation or pharyngealisation. Pettorino and Giannini (1982) report the decrease in F2 locus for both velarised lateral and pharyngealised coronal consonants. Thus F2 is still very important in pointing to emphasis, suggesting tongue retraction (Delattre 1951) to form a posterior constriction.

The location of the secondary articulation is also found to be consistent with pharyngealisation in Algerian Arabic (Marçais 1948 as cited in Card 1983), Iraqi Arabic (Al-Ani 1970; Giannini and Pettorino 1982), Tunisian Arabic (Ghazali 1977), Sudanese Arabic (Ahmed 1984), Qatari Arabic (Bukshaisha 1985), and Jordanian Arabic (Kuriyagawa et al 1988; Al-Halees 2003). The emphatics can also be uvularised in Jordanian Arabic (Al-Nassir 1993; Zawaydeh 1998), Moroccan Arabic (Zeroual 1999). On the other hand, claims have been raised so as to consider the emphatics as velarised in Egyptian Arabic (Gairnder 1925) and Lebanese Arabic (Nasr 1959), among others; these claims are based on impressionistic views. Some researchers may also be influenced by the traditional view whereby emphatics are seen as velarised consonants (Al-Nassir 1993). This does not mean that velarisation can not occur as a secondary articulation for the emphatic consonants. As discussed earlier in this section acoustic analysis of formant frequency can suggest velarisation.

In order to avoid such disagreement over the realisation of the secondary articulation, it may be better to regard it as dialect-specific. Moreover, understanding of the secondary articulation needs not to be biased towards one view or the other, but rather on exploring the phonetic information of the emphatics at articulatory and acoustic levels. If articulatory and acoustic studies are conducted for the emphatics in different Arabic dialects, dialect-specific information about the nature of the secondary articulation can be obtained. In addition to dialectal differences, there are differences within speakers due to factors like age, gender and class.

The emphatic consonants in LA can be distinguished from their plain counterparts by the degree of CV coarticulation as elicited from the LE slope results. This distinction is better reflected by the overall results. In this case the emphatic consonants have flatter slopes than their plain counterparts; this suggests more CV coarticulation resistance for the emphatic consonants than for their plain counterparts (Krull 1987, 1988, 1989). This pattern is reported for Egyptian Arabic (Sussman et al 1993), Jordanian, Kuwaiti, Yemeni and Modern Standard Arabic, but not Moroccan Arabic (Embarki et al 2007) and Modern standard Arabic (Yeou 1997; Embarki 2006). The results from this study and most Arabic dialects are predicted by the models which account for coarticulation resistance as secondary articulations can impose a constraint on the tongue body (Bladon and Al-Bamerni 1976; Recasens et al 1997; Recasens 1984, 1985, 1987, 1991). The exceptional pattern for Moroccan Arabic reflects the dialect-specific nature of coarticulation and the fact that coarticulation resistance could not be taken for granted as a universal principle (Bladon and Al-Bamerni 1976). Although the general patterns show that emphasis can resist C-to-V coarticulation in LA, it should yet be taken into consideration that this pattern could vary across speakers or different consonantal types (see discussion in this chapter, section 7.3).

The durational parameters investigated in this study are not equally important in characterising the feature emphasis in LA. The most important parameter is VOT which is found to be lower for /tˤ/ than for /t/. In general, this pattern is found to be consistent in most Arabic dialects, e.g., Tunisian Arabic (Ghazali 1977), Jordanian Arabic (Khattab et al 2006), Moroccan Arabic (Zeroual 1999), Qatari Arabic (Bukshaisha 1985) and Yemeni Arabic (Al-Nuzaili 1993). This can be explained by the role of the pharyngeal constriction in affecting the glottal activities by narrowing the glottis (Esling 1996, 1999; Esling and Harris 2003; Esling et al 2005). This is confirmed by fiberscopic studies whereby the shorter VOT for the pharyngealized /tˤ/ is accompanied by a narrow glottal opening in comparison with the non-pharyngealized /t/ (El-Halees 1989; Zeroual 1999).

The other durational parameters are of less importance to the plain emphatic distinction than VOT or of no importance at all. In fact, emphasis is supposed to have an increasing effect on the duration of the consonants and the vowels in their context as a function of the tense articulation of the emphatic consonants (Ali and Daniloff 1972a; Bukshaisha 1985). Closure duration is found to show the plain-emphatic distinction; CD is longer for /tˤ/ than for /t/ in LA (this study), Qatari Arabic (Bukshaisha 1985) and Yemeni Arabic (Al-Nuzaili 1993). Although the CD difference between the two contexts is small, it is significant. More importantly, the long closure duration for /tˤ/ seems to be relevant to the tense articulation of emphasis due to the secondary articulation although, as will be discussed later in this section, CD enters into a temporal relationship with VOT and VD.

On the other hand, the assumption concerning the tense articulation of the emphatics does not seem to be relevant to the LA emphatic /sˤ/ whose intensity and duration are not significantly different from the intensity and duration of the plain /s/. Generally speaking, the /s/-/sˤ/ durational difference does not show a consistent pattern that leads to the distinction between the contrast in the Arabic dialects investigated apart from Qatari Arabic (Bukshaisha 1985) (for more details, see section 7.4 in this chapter).

Although the vowel duration difference between the plain and emphatic contexts is significant, it does not seem to be of a perceptual importance, and may not lead to the plain-emphatic distinction in Libyan Arabic. This is because of two reasons. Firstly, the difference between the two contexts is small. In fact, in the vast majority of Arabic dialects surveyed the difference is not significant, e.g., Iraqi Arabic (Ali and Daniloff 1972b) and Egyptian Arabic (El-Dalee 1984; Norlin 1987). Secondly, an inconsistent pattern is observed for different consonantal types in this study. The vowel duration difference is found to be significant only in the context of the /t/-/tˤ/ contrast, but not in the /sˤ/-/s/ and /dˤ/-/d/ contrasts. Similarly Hussain (1985) reported a longer vowel duration only in the context of /tˤ/ compared to that of /t/. This, according to Hussain (1985), is attributed to the long aspiration for /t/. In fact, CD, VOT and VD in the context of the /t/-/tˤ/ contrast enter into a temporal relationship given that the total duration of these three acoustic parameters is similar for both plain and emphatic contexts. The overall CV syllable does not show any lengthening effect of emphasis. Thus the secondary articulation of the emphatics in LA may not cause the emphatics to be tense articulations if taking into consideration that tense articulations exhibit long duration. The temporal relationship also applies to the /s/-/sˤ/ contrast whereby the CV duration is similar for both contexts.

This section has shown that the most important formant frequency in the plain emphatic distinction is F2 followed by F1 and F3. Generally speaking, the emphatic consonants are characterised by more CV coarticulation resistance than their plain counterparts. The durational cue that distinguishes the emphatic from its plain counterpart the most is VOT followed by CD and VD for the /t/-/tˤ/ contrast. The general pattern of vowel duration shows a tendency towards a significant increase in the emphatic context, but this increase is slight and inconsistent across different consonantal types. The duration and absolute intensity differences between /s/ and /sˤ/ are of no significant importance to the plain emphatic distinction.

7.6. Limitation of the study and suggestions for further investigations

This study has not covered all the acoustic parameters related to the emphatics. VOT and CD for /d/ and /dˤ/ were not investigated. Results for Libyan Arabic and other Arabic dialects have shown that both /d/ and /dˤ/ are associated with voicing lead and there is a considerable overlap between VOT for both (Yeni-Komshian et al 1977; Al-Nuzaili 1993; Kriba 2004). This may be the reason why the vast majority of studies on the effect of emphasis on VOT are concerned with the voiceless stops in which VOT could play a role in distinguishing /t/ from /tˤ/ in most Arabic dialects (see section 7.4 in this chapter).

It may be of interest for a further study to measure the total CV duration for /d/ and /dˤ/ (this will include CD, VOT and VD) in order to find out whether the temporal relation reported for the /t/-/tˤ/ and /s/-/sˤ/ contrasts is detected in the case of the /d/-/dˤ/ contrast. Moreover, an investigation of the temporal relationship for all consonantal types in different Arabic dialects may reveal whether this relationship exists for the plain and emphatic contexts.

The acoustic analysis may be better accompanied by articulatory work since the emphatic consonants involve complex articulations which yield different acoustic effects as discussed in this chapter, section 7.2. This makes it possible to correlate articulatory with acoustic results. In this case, it will be possible to avoid any counteracting effect that may lead to misinterpretation of acoustic data. For instance, lip rounding, which is associated with the production of the emphatic consonant, could lower the first three formant frequencies and thus enhance F2 lowering that is triggered by emphasis, but counteract the tendency of emphasis to increase F1 and F3. To elicit data from the same speakers in a combination of an acoustic and articulatory study of LA could reveal more closely the realisation of the secondary articulation of the emphatics, the articulatory-acoustic relation, speaker variation and the effect of vowel context in the realisation of emphasis. A cross-dialectal investigation of this nature, which is carried out under the same conditions, could also show how the articulation of the emphatics is realised cross-dialectally.

It would also be interesting to combine a production and perception study on the emphatic consonants on the same speakers in order to find out whether the acoustic variability in the production of the plain and emphatic consonants is reflected in the acoustic boundaries at which speakers perceive the emphatic consonant as being different from its plain counterpart. For instance does variation in F2 patterns observed in production match those observed in perception for a given speaker?

An examination of the plain-emphatic distinction in longer utterances containing more than a syllable in addition to examining the emphatics in different positions (initial, medial and final) may also enhance the role of some factors in the plain emphatic distinction. This would also provide information about the extent to which the emphatic gesture can spread leftward and rightward.

An investigation of some acoustic parameters that have not been covered in this study may lead to the plain-emphatic distinction. These include the fundamental frequency, the intensity of the stop burst and the spectral shape of the spectrum based on static information on the consonant or on the overall shape of the spectrum (spectral moments) which include center of gravity, spectral standard deviation, skewness and kurtosis.

It may also be of interest to extend the application of LE parameters and the other acoustic parameters investigated in this study to the plain and emphatic consonants in longer utterances and in different positions in addition to other LA consonantal types like bilabials, palatals, velars, uvulars and pharyngeals with different manners of articulation and voicing state in order to assess their contribution in categorising these consonantal classes.

A socio-phonetic study of gender and social class could show whether the realisation of emphasis is affected by a number of social variables. Thus it would be interesting to look at females in this study and to look at other Libyan dialects and investigate the potential effect of social class and/or education. This will enrich the existing literature as phonetic studies related to gender are non-existent in Libyan Arabic.

It is reported that children tend to master the production of the coronal plain consonants first and later acquire their emphatic counterparts. Studies on the acquisition of the emphatics are rare on Arabic in general and absent on Libyan Arabic in particular. Thus in further studies the acquisition of the emphatics may deserve a longitudinal phonetic investigation so as to observe how the children gradually acquire the emphatics following mastery of their plain counterparts.

7.7. Conclusion

Results from the current study have shown that some acoustic parameters could distinguish emphatic from plain consonant. These include the first three formant frequencies in the following vowel; F1 and F3 increase in the emphatic context while F2 decreases. These results are triggered by the presence of the secondary articulation of the emphatics, which is represented by the tongue retraction towards the back wall of the pharynx. The exception to this tendency is the F3 decrease observed for the high front vowel /iː/ in the emphatic context. This deviant behaviour may be expected if taking into account that /iː/ resists coarticulation with the emphatic gesture and slight tongue retraction is observed in its production in Libyan Arabic (Laradi 1983). The most influenced formant frequency by emphasis is F2 followed by F1 and F3. The effect of emphasis which depends on vowel quality and quantity is more pronounced at the onset than the midpoint of adjacent vowels.

This study also investigated the role of locus equations (LE) in the plain emphatic distinction through the regression analysis of F2 onset and F2 midpoint. Generally speaking, the LE slope and y-intercept are lower for the emphatic (due to the presence of the secondary articulation) than for the plain context. The low slope suggests that the emphatic consonants resist coarticulation with the following vowel more than their plain counterparts and the low y-intercept reflects the low F2 onset for the emphatic context. The slope and y-intercept results are not always consistent across different speakers and consonantal types. For only some speakers, the slope and y-intercept are higher in the emphatic than in the plain context. The voiced consonants are found to resist coarticulation with the following vowels more than the voiceless ones, reflecting the effect of voicing state on the degree of coarticulation.

This study has also looked at the role of various vocalic and consonantal duration parameters in the plain-emphatic distinction. The emphatic /tˤ/ has shorter VOT than the plain /t/ due to the effect of emphasis on the laryngeal activities as the glottis is narrower in the production of /tˤ/ than /t/. On the other hand, closure and vowel duration are longer in the /t/ than in the /tˤ/ context. Although these results seem to suggest an effect of emphasis, the total duration of CD, VOT and VD are similar for both the plain and emphatic contexts, suggesting the presence of a temporal relationship between the three acoustic parameters. Such a relation is also detected in the fricative environment. The fact that the emphatic fricative is longer than its plain counterpart as a function of the greater intensity for the former as suggested in the literature is not applicable to our results in which the durational and intensity differences are not significant.

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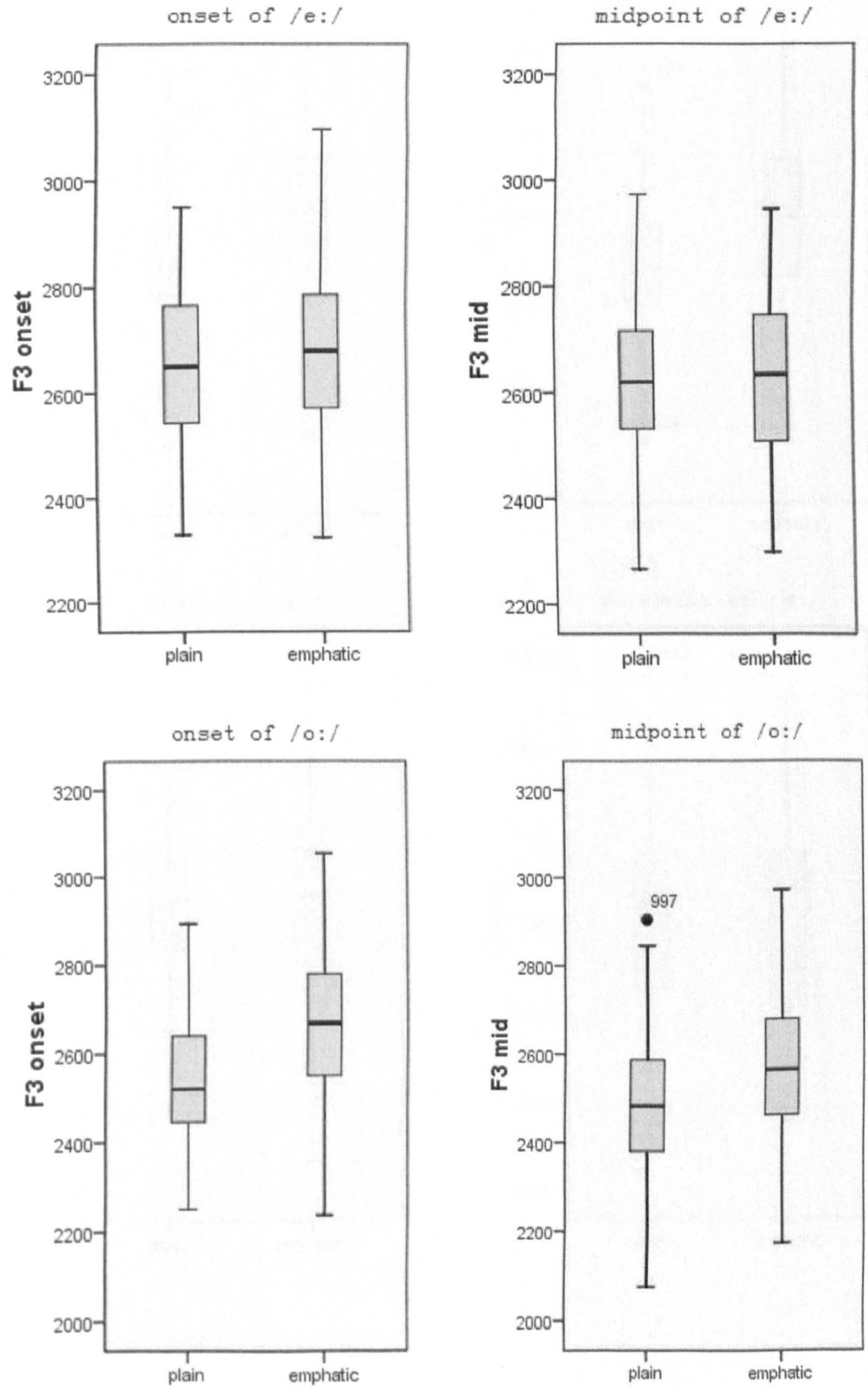
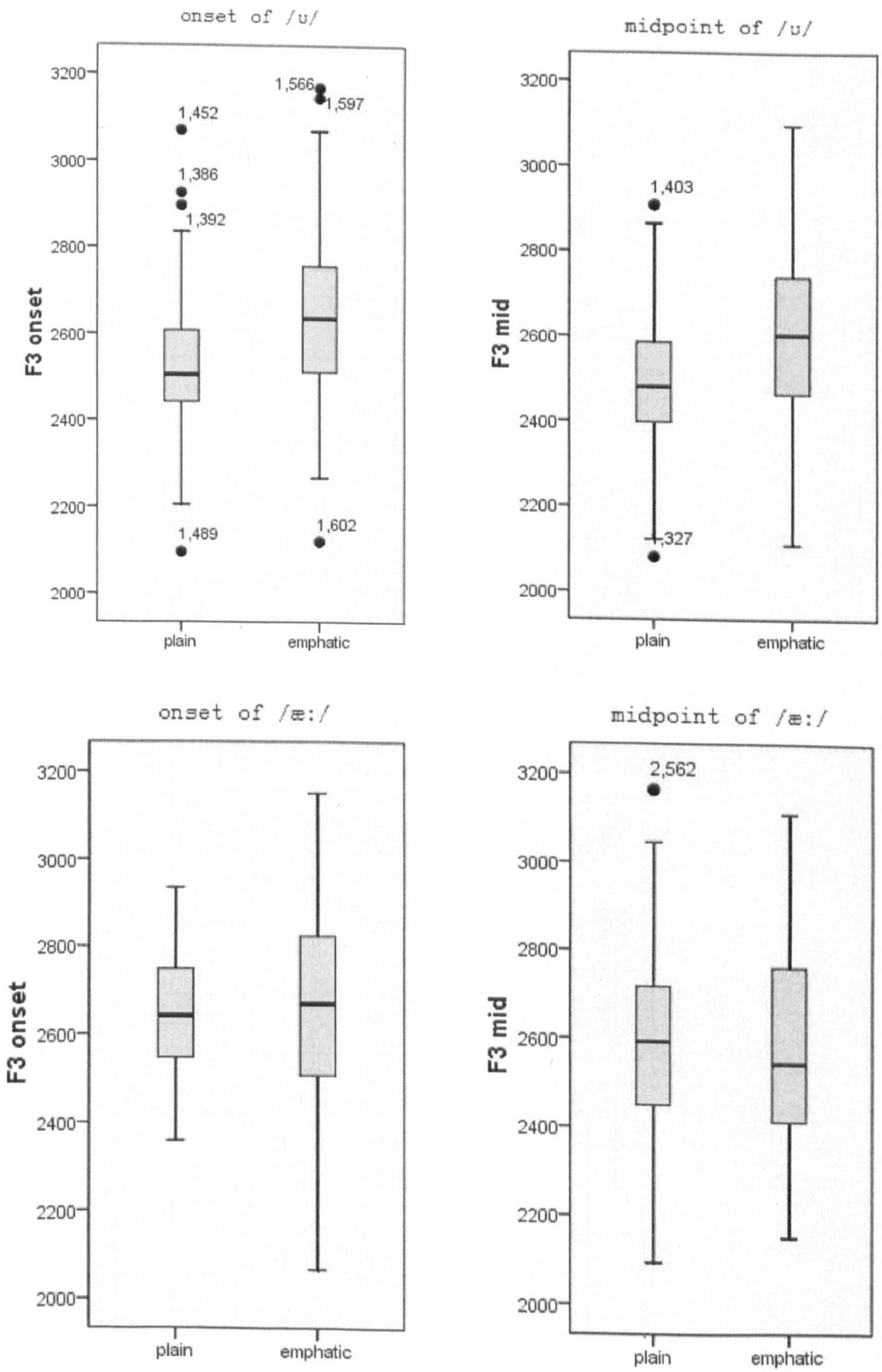
Appendix 1

F3 (in Hz) for some vowels in plain and emphatic contexts





onset of /ʊ/
F3 onset
3200
3000
2800
2600
2400
2200
2000
1,452
1,386
1,392
1,489
1,566
1,597
1,602
plain
emphatic
midpoint of /ʊ/
F3 mid
3200
3000
2800
2600
2400
2200
2000
1,403
327
plain
emphatic
onset of /æ:/
F3 onset
3200
3000
2800
2600
2400
2200
2000
plain
emphatic
midpoint of /æ:/
F3 mid
3200
3000
2800
2600
2400
2200
2000
2,562
plain
emphatic

Appendix 2
Mean F1, F2 and F3 in different consonantal contexts

Vowel	/iː/		/ɪ/		/eː/		/oː/		/ʊ/		/uː/		/ɛ/		/æː/	
context	/t/	/tˤ/	/t/	/tˤ/	/t/	/tˤ/	/t/	/tˤ/	/t/	/tˤ/	/t/	/tˤ/	/t/	/tˤ/	/t/	/tˤ/
F1 onset	328	372	398	442	379	453	436	468	416	452	362	397	490	545	495	556
F2 onset	2137	1620	1808	1282	1941	1431	1365	1008	1384	1017	1307	960	1670	1139	1687	1141
F3 onset	2791	2694	2638	2705	2689	2683	2540	2648	2512	2621	2438	2720	2634	2635	2665	2652
F1 mid	355	369	431	478	443	456	495	502	453	477	372	390	533	593	606	633
F2 mid	2186	2065	1780	1376	1886	1790	1089	987	1327	1039	979	876	1622	1203	1549	1184
F3 mid	2767	2677	2611	2686	2637	2626	2535	2584	2505	2584	2474	2647	2608	2606	2581	2567
context	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/
F1 onset	314	352	369	405	357	425	404	430	364	425	337	367	442	491	419	499
F2 onset	2030	1601	1733	1278	1889	1370	1516	1119	1524	1089	1563	1088	1646	1151	1732	1146
F3 onset	2743	2689	2624	2682	2620	2692	2569	2704	2537	2642	2466	2640	2619	2680	2657	2750
F1 mid	330	347	412	435	440	460	481	491	408	458	357	375	516	563	583	620
F2 mid	2116	2023	1688	1244	1906	1704	1212	1064	1343	984	1063	938	1563	1129	1594	1168
F3 mid	2782	2693	2591	2738	2623	2646	2529	2602	2477	2618	2468	2580	2606	2684	2602	2629
context	/s/	/sˤ/			/s/	/sˤ/	/s/	/sˤ/	/s/	/sˤ/	/s/	/sˤ/	/s/	/sˤ/	/s/	/sˤ/
F1 onset	316	349			390	439	436	459	408	438	360	387	498	543	474	548
F2 onset	2075	1821			1843	1490	1354	1074	1429	1112	1361	1074	1563	1168	1660	1181
F3 onset	2728	2676			2620	2654	2552	2656	2547	2658	2558	2717	2600	2587	2647	2651
F1 mid	328	343			449	464	488	507	432	458	365	393	548	588	589	638
F2 mid	2164	2090			1859	1742	1085	986	1385	1097	1155	938	1495	1154	1562	1205
F3 mid	2740	2673			2598	2606	2507	2574	2526	2620	2535	2635	2541	2570	2588	2583

Appendix 3

Statistical tests for formant frequencies

Appendix 3A: Independent sample t-tests for F1 and F2 onset

F1 onset difference between plain and emphatic contexts							
/i:/	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
($t(353) = -12.593$ $p < 0.001$)	($t(232) = -8.312$ $p < 0.001$)	($t(353) = -17.438$, $p < 0.001$)	($t(358) = -7.123$, $p < 0.001$)	($t(357) = -10.376$, $p < 0.001$	($t(354) = -9.795$, $p < 0.001$	($t(355) = -10.168$, $p < 0.001$	($t(358) = -14.825$, $p < 0.001$
F2 onset difference between plain and emphatic contexts							
/i:/	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
($z = -14.214$, $p < 0.001$)	($t(233) = 19.483$, $p < 0.001$)	($z = -15.942$, $p < 0.001$)	($t(358) = 21.253$, $p < 0.001$)	($t(357) = 21.613$, $p < 0.001$)	($t(354) = 19.274$, $p < 0.001$)	($z = -16.307$, $p < 0.001$)	($z = -16.409$, $p < 0.001$)

Appendix 3B: Independent sample t-tests for F1 and F2 midpoint

F1 midpoint difference between plain and emphatic contexts							
/i:/	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
($z = -4.946$, $p < 0.001$)	($z = -6.282$, $p < 0.001$)	($t(353) = -4.199$, $p < 0.001$)	($t(358) = -3.563$, $p < 0.001$)	($z = -7.608$, $p < 0.001$)	($t(353) = -6.452$, $p < 0.001$)	($t(355) = -10.955$, $p < 0.001$)	($z = -8.272$, $p < 0.001$)
F2 midpoint difference between plain and emphatic contexts							
/i:/	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
($t(352) = 6.667$, $p < 0.001$)	($t(233) = 16.468$, $p < 0.001$)	($t(353) = 9.881$, $p < 0.001$)	($t(358) = 10.586$, $p < 0.001$)	($t(357) = 19.876$, $p < 0.001$)	($t(354) = 10.805$, $p < 0.001$)	($t(355) = 34.527$, $p < 0.001$)	($t(358) = 38.405$, $p < 0.001$)

Appendix 3C: Independent sample t-tests for F3

F3onset difference between plain and emphatic contexts							
/i:/	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
($t(353) = 5.156$, $p < 0.001$)	($z = -3.142$, $p < 0.05$)	**($t(353) = -1.793$, $p > 0.05$)**	($t(358) = -8.580$, $p < 0.001$)	($z = -6.157$, $p < 0.001$)	($t(353) = -11.920$, $p < 0.001$	**($z = -.347$, $p > 0.05$)**	**($z = -1.331$, $p > 0.05$)**
F3 midpoint difference between plain and emphatic contexts							
/i:/	/ɪ/	/e:/	/o:/	/ʊ/	/u:/	/ɛ/	/æ:/
($t(353) = 4.669$, $p < 0.001$)	($t(233) = -6.051$, $p < 0.001$)	**($t(353) = -.376$, $p > 0.05$)**	($z = -5.733$, $p < 0.001$)	($z = -5.606$, $p < 0.001$)	($t(354) = -8.171$, $p < 0.001$)	**($z = -1.117$, $p > 0.05$)**	**($z = -.462$, $p > 0.05$)**

Appendix 3D

Bonferroni post hoc tests for different consonantal contexts

F1 onset			
plain	p value	emphatic	p value
/t/-/d/	< 0.001	/tˤ/-/dˤ/	< 0.001
/t/-/s/	> 0.05	/tˤ/-/sˤ/	> 0.05
/d/-/s/	< 0.001	/dˤ/-/sˤ/	< 0.001
F2 onset			
/t/-/d/	< 0.05	/tˤ/-/dˤ/	> 0.05
/t/-/s/	< 0.05	/tˤ/-/sˤ/	< 0.001
/d/-/s/	< 0.001	/dˤ/-/sˤ/	> 0.05
F3 onset			
/t/-/d/	> 0.05	/tˤ/-/dˤ/	> 0.05
/t/-/s/	> 0.05	/tˤ/-/sˤ/	> 0.05
/d/-/s/	> 0.05	/dˤ/-/sˤ/	< 0.05
F1 midpoint			
/t/-/d/	< 0.001	/tˤ/-/dˤ/	< 0.05
/t/-/s/	> 0.05	/tˤ/-/sˤ/	> 0.05
/d/-/s/	< 0.05	/dˤ/-/sˤ/	< 0.05
F2 midpoint			
/t/-/d/	> 0.05	/tˤ/-/dˤ/	> 0.05
/t/-/s/	> 0.05	/tˤ/-/sˤ/	> 0.05
/d/-/s/	> 0.05	/dˤ/-/sˤ/	> 0.05
F3 midpoint			
/t/-/d/	> 0.05	/tˤ/-/dˤ/	> 0.05
/t/-/s/	> 0.05	/tˤ/-/sˤ/	> 0.05
/d/-/s/	> 0.05	/dˤ/-/sˤ/	< 0.05

Appendix 4

Auditory analysis of vowels in plain and emphatic contexts

vowel	/iː/		/ɪ/		/eː/		/oː/		/ʊ/		/uː/		/ɛ/		/æː/	
speakers	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic
1	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ə]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ə]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ə]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[ɛː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
					[eː]	[e̞ː]		[o̞ː]		[ʊ̞]	[uː]	[u̞ː]				
2	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[iː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
3	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ə]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]
	[iː]	[i̞ː]	[ɪ]	[ᵻ]	[eː]	[e̞ː]	[oː]	[o̞ː]	[ʊ]	[ʊ̞]	[uː]	[u̞ː]	[ɛ]	[ʌ]	[æː]	[ɐ̞ː]

4	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
5	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ə]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[ɛ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[ɛ:]	[ɐ̝:]
6	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ə]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ə]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɪ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
			[ɪ]		[e:]	[e̝:]										
7	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]

	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ʌ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
			[ɪ]	[ɨ]	[e:]	[e̟:]		[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]				
8	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[ɛ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
			[ɪ]		[e:]	[e̟:]		[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]				
9	[i:]	[i̟:]	[ɪ]	[ʌ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɪ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
			[ɪ]		[e:]	[e̟:]				[ʊ̟]	[u:]	[u̟:]				
10	[i:]	[i̟:]	[ɪ]	[ʊ̟]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ʌ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ʊ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ɪ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]
	[i:]	[i̟:]	[ɪ]	[ɨ]	[e:]	[e̟:]	[o:]	[o̟:]	[ʊ]	[ʊ̟]	[u:]	[u̟:]	[ɛ]	[ʌ]	[æ:]	[ɐ̟:]

	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
11	[i:]	[i̝:]	[ɛ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ʌ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ə]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[ɛ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[ɛ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
12	[i:]	[i̝:]	[ɪ]	[ʌ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
13	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
14	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ə]	[ʌ]	[æ]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ]	[ɐ̝:]

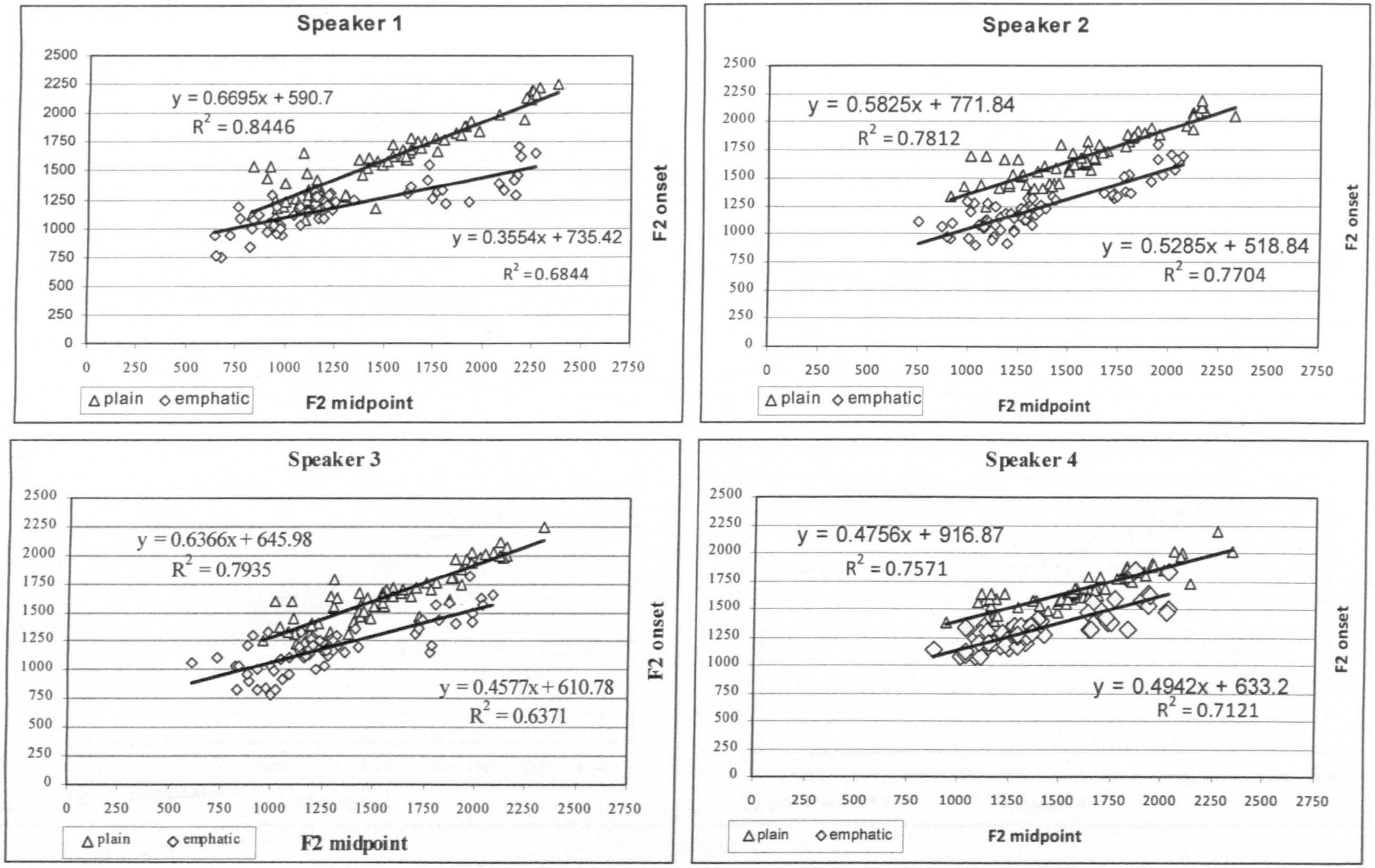
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
15	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
16	[i:]	[e:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ɪ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
17	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ɪ]	[ʊ̞]	[u:]	[u̞:]	[ə]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ə]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]
	[i:]	[i̞:]	[ɪ]	[ɨ]	[e:]	[e̞:]	[o:]	[o̞:]	[ʊ]	[ʊ̞]	[u:]	[u̞:]	[ɛ]	[ʌ]	[æ:]	[ɐ̞:]

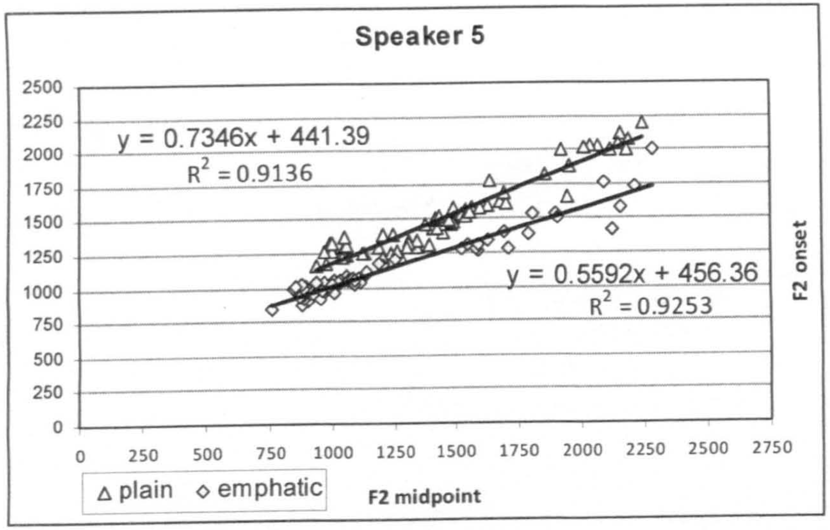
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
18	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ̝:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[ɛ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
19	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[ɛ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
20	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]
	[i:]	[i̝:]	[ɪ]	[ɨ]	[e:]	[e̝:]	[o:]	[o̝:]	[ʊ]	[ʊ̝]	[u:]	[u̝:]	[ɛ]	[ʌ]	[æ:]	[ɐ̝:]

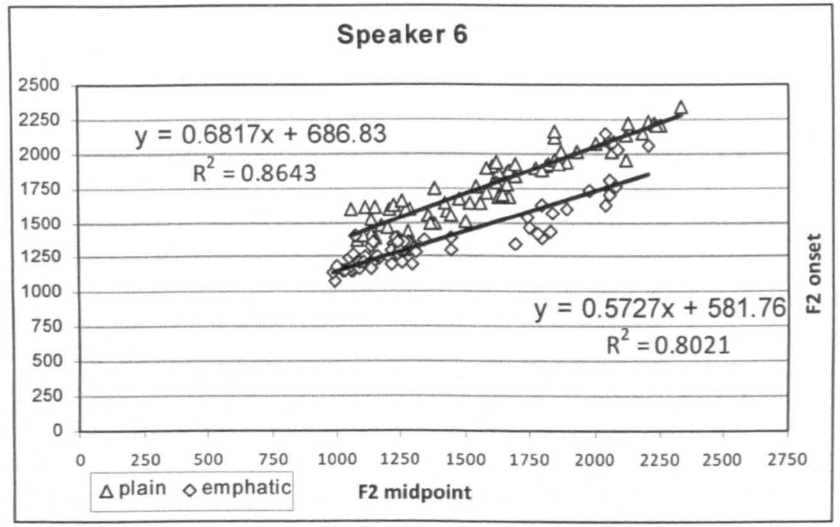
The most frequently occurring plain and emphatic allophones in percentage																
vowel	/i:/		/ɪ/		/e:/		/o:/		/ʊ/		/u:/		/ɛ/		/æ:/	
context	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic	plain	emphatic
variant	[i:]	[i̙:]	[ɪ]	[ɨ]	[e:]	[e̙:]	[o:]	[o̙:]	[ʊ]	[ʊ̙]	[u:]	[u̙:]	[ɛ]	[ʌ]	[æ:]	[ɐ̙:]
number of tokens	180	179	118	115	179	180	180	180	177	180	180	180	166	180	169	174
%	100	99.4	98.3	95.8	99.4	100	100	100	98.3	100	100	100	92.2	100	93.8	96.6

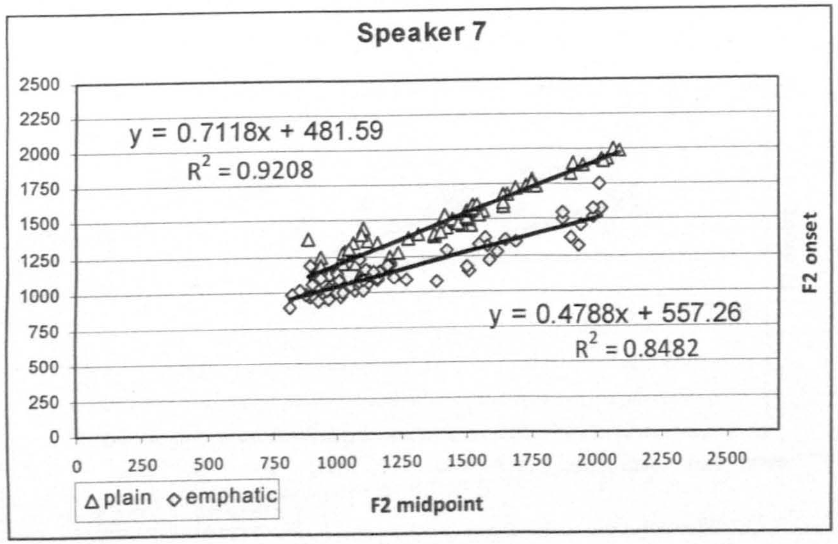
Appendix 5

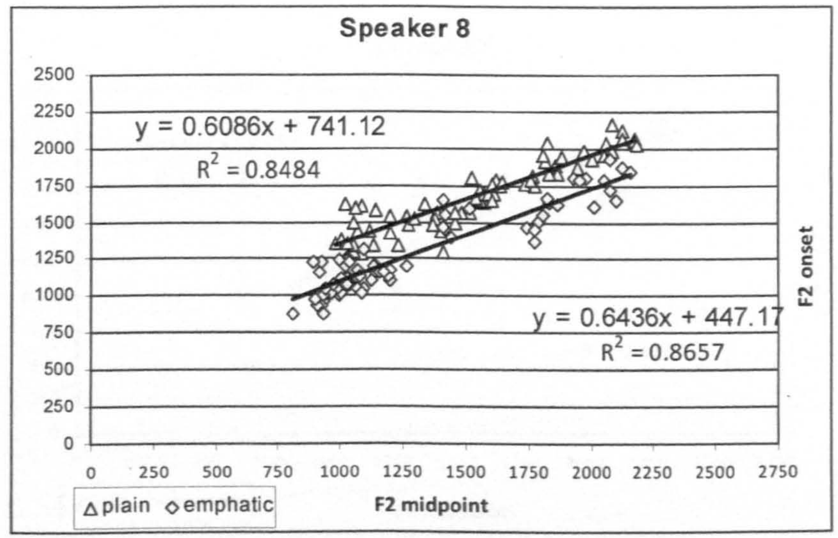
The slope of the LE regression line for each speaker

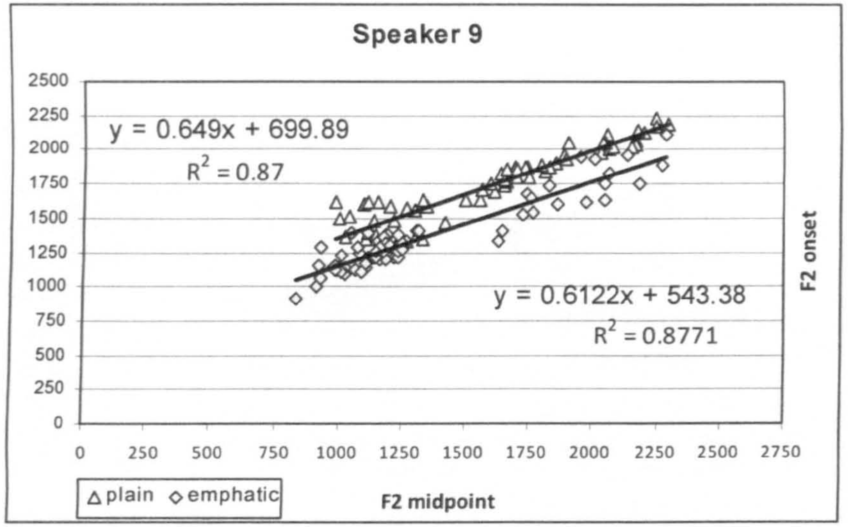


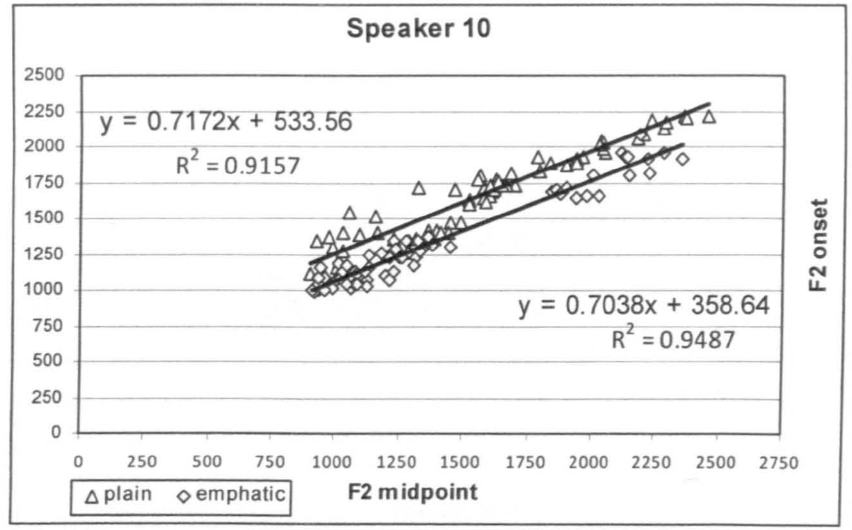

Speaker 5
y = 0.7346x + 441.39
R2 = 0.9136
y = 0.5592x + 456.36
R2 = 0.9253
F2 onset
F2 midpoint
plain
emphatic

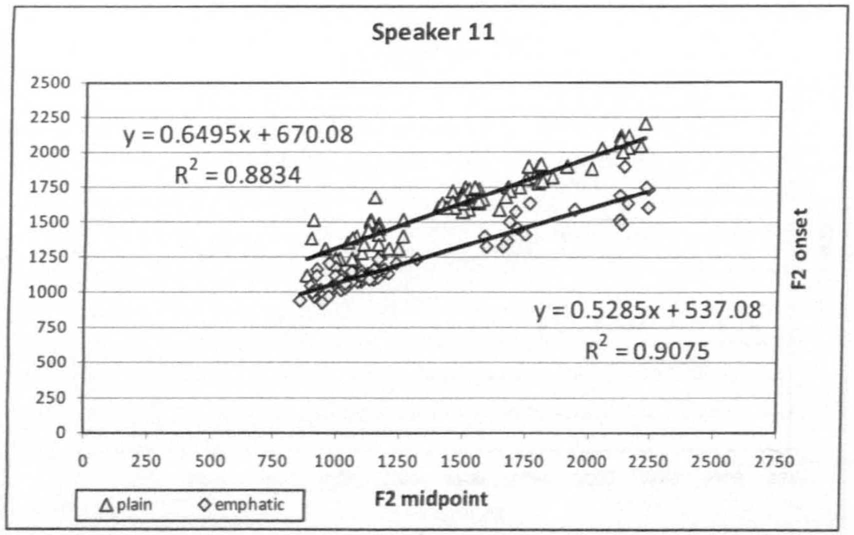

Speaker 6
y = 0.6817x + 686.83
R2 = 0.8643
y = 0.5727x + 581.76
R2 = 0.8021
F2 onset
F2 midpoint
plain
emphatic

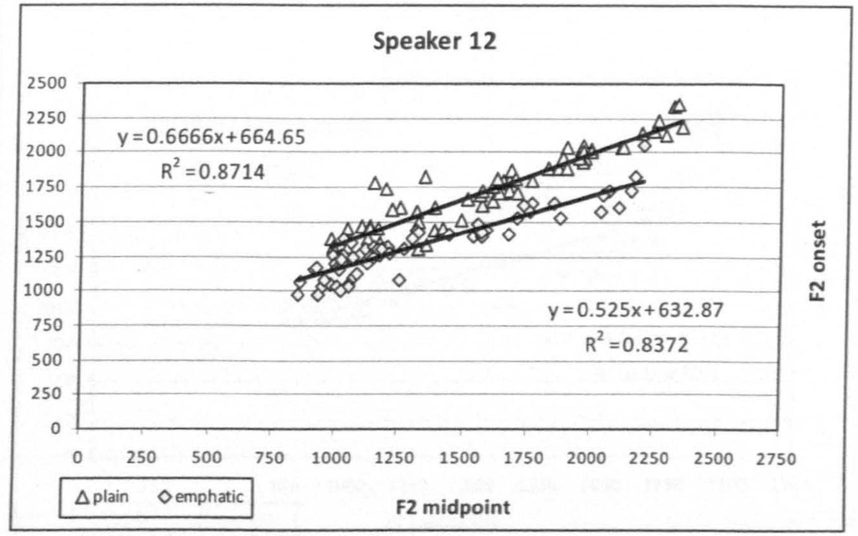

Speaker 7
y = 0.7118x + 481.59
R2 = 0.9208
y = 0.4788x + 557.26
R2 = 0.8482
F2 onset
F2 midpoint
plain
emphatic

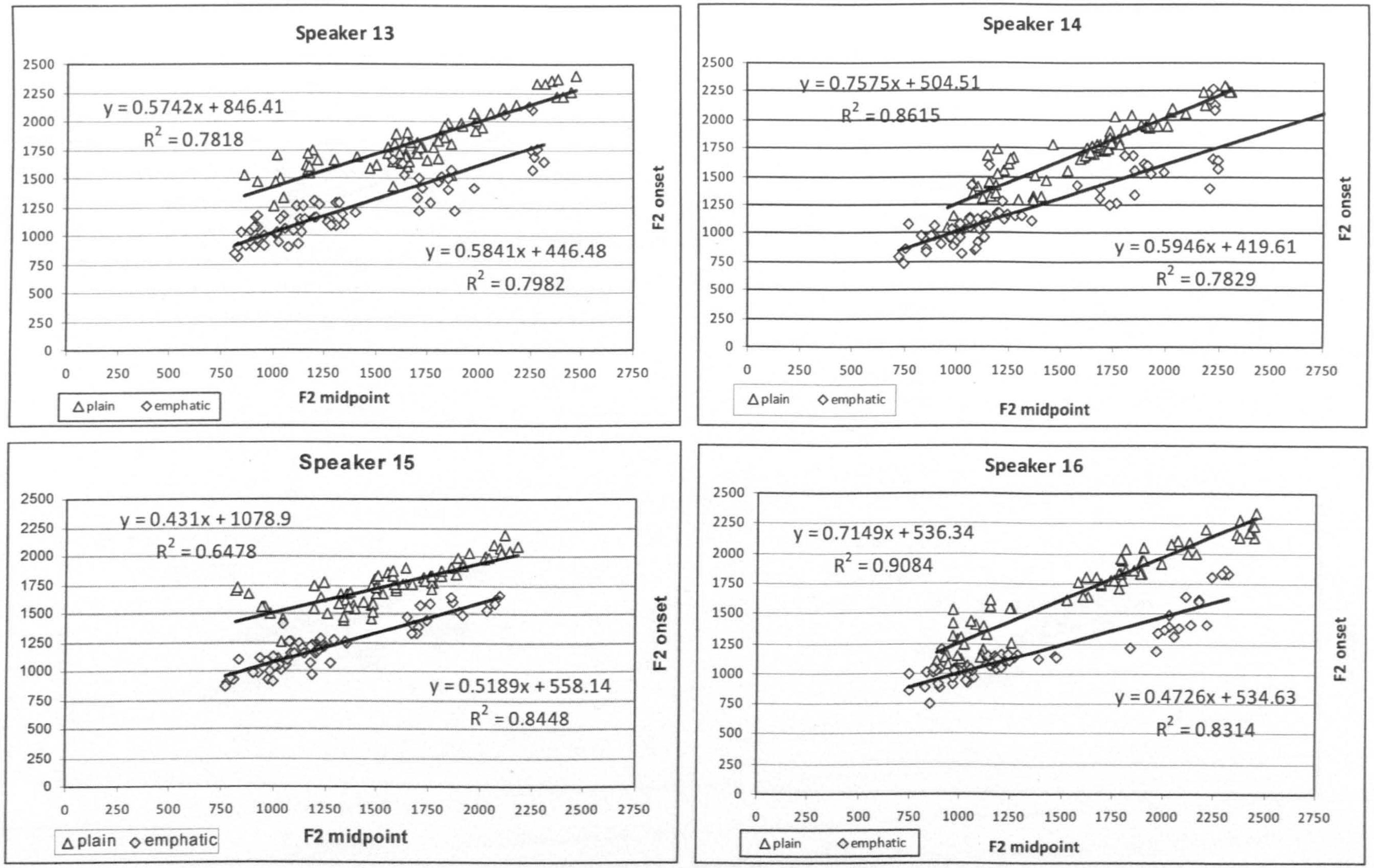

Speaker 8
y = 0.6086x + 741.12
R2 = 0.8484
y = 0.6436x + 447.17
R2 = 0.8657
F2 onset
F2 midpoint
plain
emphatic


Speaker 9
y = 0.649x + 699.89
R² = 0.87
y = 0.6122x + 543.38
R² = 0.8771
F2 onset
F2 midpoint
△plain ◇emphatic
0 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750

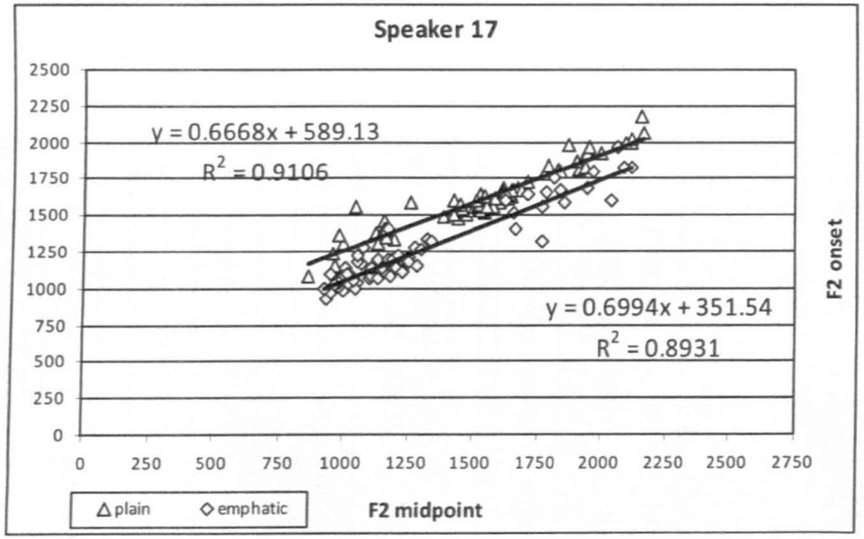

Speaker 10
y = 0.7172x + 533.56
R² = 0.9157
y = 0.7038x + 358.64
R² = 0.9487
F2 onset
F2 midpoint
△plain ◇emphatic
0 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750

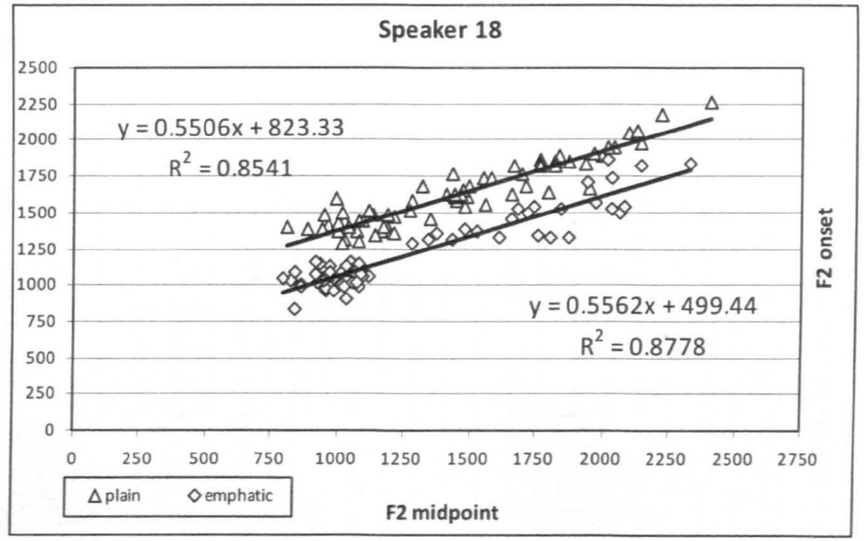

Speaker 11
y = 0.6495x + 670.08
R² = 0.8834
y = 0.5285x + 537.08
R² = 0.9075
F2 onset
F2 midpoint
△plain ◇emphatic
0 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750

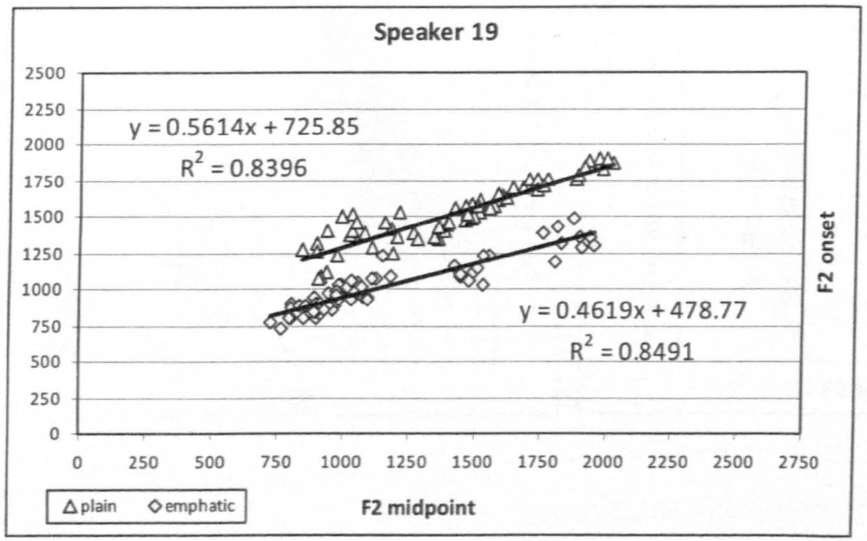

Speaker 12
y = 0.6666x + 664.65
R² = 0.8714
y = 0.525x + 632.87
R² = 0.8372
F2 onset
F2 midpoint
△plain ◇emphatic
0 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750

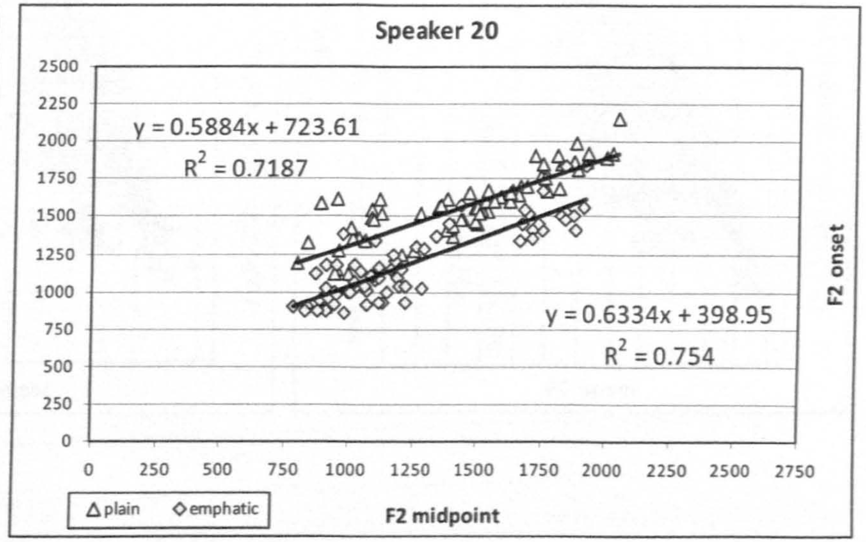


Speaker 13
y = 0.5742x + 846.41
R² = 0.7818
y = 0.5841x + 446.48
R² = 0.7982
F2 onset
F2 midpoint
plain
emphatic
Speaker 14
y = 0.7575x + 504.51
R² = 0.8615
y = 0.5946x + 419.61
R² = 0.7829
F2 onset
F2 midpoint
plain
emphatic
Speaker 15
y = 0.431x + 1078.9
R² = 0.6478
y = 0.5189x + 558.14
R² = 0.8448
F2 onset
F2 midpoint
plain
emphatic
Speaker 16
y = 0.7149x + 536.34
R² = 0.9084
y = 0.4726x + 534.63
R² = 0.8314
F2 onset
F2 midpoint
plain
emphatic


Speaker 17
y = 0.6668x + 589.13
R² = 0.9106
y = 0.6994x + 351.54
R² = 0.8931
F2 onset
F2 midpoint
△ plain ◇ emphatic

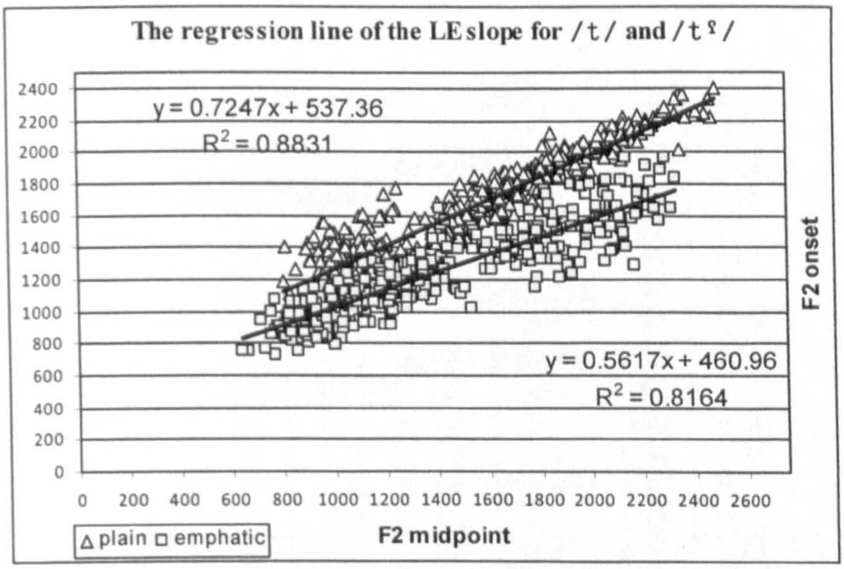

Speaker 18
y = 0.5506x + 823.33
R² = 0.8541
y = 0.5562x + 499.44
R² = 0.8778
F2 onset
F2 midpoint
△ plain ◇ emphatic

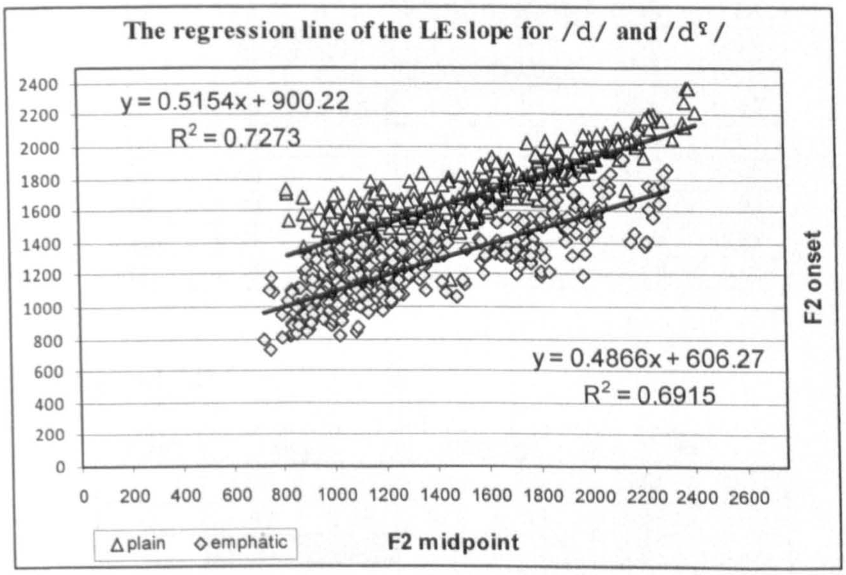

Speaker 19
y = 0.5614x + 725.85
R² = 0.8396
y = 0.4619x + 478.77
R² = 0.8491
F2 onset
F2 midpoint
△ plain ◇ emphatic

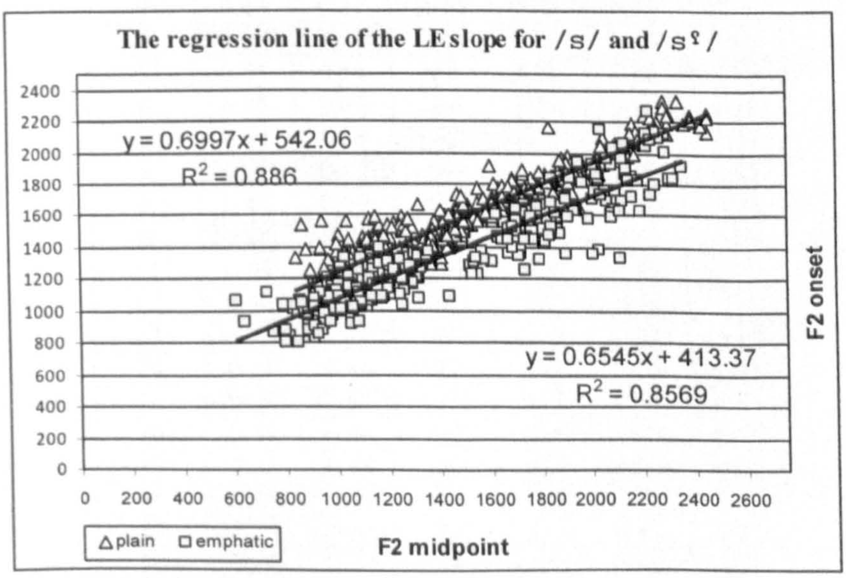

Speaker 20
y = 0.5884x + 723.61
R² = 0.7187
y = 0.6334x + 398.95
R² = 0.754
F2 onset
F2 midpoint
△ plain ◇ emphatic

Appendix 6a

The slope of the LE regression line for each consonantal type







Appendix 6b

LE parameters for different consonants produced by each speaker

- LE parameters for /t/ and /tˤ/

subjects	slope		intercept		R^2	
	/t/	/tˤ/	/t/	/tˤ/	/t/	/tˤ/
1	0.72	0.38	527	692	0.93	0.72
2	0.64	0.64	661	330	0.91	0.88
3	0.76	0.56	446	385	0.91	0.80
4	0.56	0.47	783	607	0.86	0.84
5	0.76	0.50	430	502	0.93	0.94
6	0.71	0.53	640	603	0.87	0.90
7	0.76	0.50	388	504	0.95	0.94
8	0.70	0.75	620	293	0.91	0.90
9	0.69	0.66	644	435	0.88	0.96
10	0.73	0.68	515	362	0.94	0.96
11	0.77	0.49	490	556	0.93	0.93
12	0.77	0.55	942	549	0.93	0.90
13	0.65	0.50	702	492	0.83	0.88
14	0.92	0.57	207	477	0.98	0.84
15	0.46	0.56	1077	495	0.80	0.94
16	0.86	0.46	270	494	0.96	0.91
17	0.76	0.79	443	214	0.96	0.96
18	0.60	0.49	743	531	0.92	0.92
19	0.60	0.42	686	495	0.91	0.90
20	0.72	0.66	543	307	0.88	0.80
mean	**0.71**	**0.56**	**588**	**466**	**0.91**	**0.89**
SD	*0.10*	*0.11*	*210*	*119*	*0.05*	*0.06*

- LE parameters for /d/ and /dˤ/

subject	slope		intercept		R^2	
	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/
1	0.47	0.29	923	887	0.65	0.67
2	0.35	0.43	1186	676	0.67	0.65
3	0.43	0.27	1040	909	0.76	0.55
4	0.32	0.40	1182	753	0.63	0.80
5	0.65	0.54	556	488	0.88	0.96
6	0.56	0.40	920	804	0.90	0.71
7	0.61	0.38	667	675	0.91	0.71
8	0.44	0.47	1048	720	0.85	0.83
9	0.47	0.35	1027	918	0.90	0.76
10	0.64	0.72	707	374	0.88	0.96
11	0.49	0.48	934	599	0.86	0.93
12	0.46	0.42	1047	797	0.73	0.69
13	0.48	0.57	1056	460	0.74	0.82
14	0.51	0.46	963	508	0.79	0.62
15	0.26	0.47	1372	612	0.50	0.68
16	0.58	0.43	823	594	0.91	0.75
17	0.63	0.58	648	487	0.94	0.91
18	0.45	0.56	984	519	0.80	0.85
19	0.39	0.41	996	573	0.68	0.76
20	0.30	0.53	1183	528	0.44	0.75
mean	**0.47**	**0.46**	**963**	**644**	**0.77**	**0.77**
SD	*0.11*	*0.11*	*204*	*160*	*0.14*	*0.11*

- LE parameters for /s/ and /sˤ/

subject	slope		intercept		R^2	
	/s/	/sˤ/	/s/	/sˤ/	/s/	/sˤ/
1	0.79	0.40	366	624	0.97	0.83
2	0.79	0.53	411	544	0.92	0.84
3	0.63	0.51	578	588	0.90	0.79
4	0.48	0.66	894	489	0.75	0.85
5	0.78	0.67	363	349	0.94	0.96
6	0.80	0.74	464	399	0.91	0.90
7	0.73	0.56	423	498	0.96	0.95
8	0.66	0.70	598	344	0.92	0.96
9	0.78	0.75	447	374	0.96	0.97
10	0.77	0.73	403	310	0.97	0.96
11	0.68	0.61	602	470	0.95	0.94
12	0.66	0.57	641	605	0.95	0.95
13	0.56	0.76	832	309	0.83	0.92
14	0.79	0.66	428	392	0.91	0.88
15	0.58	0.51	782	589	0.82	0.92
16	0.67	0.51	571	532	0.96	0.91
17	0.53	0.79	818	284	0.77	0.88
18	0.56	0.65	790	420	0.83	0.95
19	0.62	0.56	605	371	0.91	0.95
20	0.68	0.71	550	370	0.84	0.85
mean	**0.68**	**0.63**	**578**	**443**	**0.90**	**0.91**
SD	*0.10*	*0.11*	*169*	*109*	*0.07*	*0.05*

Appendix 7a

Slope and y-intercept values for different Arabic varieties and dialects

mean c and k values for MSA (speakers from four dialects) (Embarki et al 2007)									
		/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
Jordanian speakers	c	***296***	***401***	430	***202***	***549***	***503***	361	***411***
	k	0.847	0.751	0.772	0.851	0.460	0.540	0.664	0.552
Kuwaiti speakers	c	643	659	299	***447***	493	528	224	***543***
	k	0.666	0.653	0.840	0.739	0.515	0.471	0.788	0.442
Moroccan speakers	c	***373***	569	***278***	***393***	***402***	427	***286***	***412***
	k	0.787	0.685	0.822	0.756	0.670	0.646	0.792	0.610
Yemeni speakers	c	***388***	449	409	477	571	420	257	450
	k	0.795	0.745	0.772	0.722	0.426	0.541	0.751	0.490
mean for all speakers	c	***423***	515	335	***385***	***473***	434	262	***420***
	k	0.773	0.712	0.813	0.765	0.545	0.573	0.766	0.555
mean c and k values from four Arabic dialects (Embarki et al 2007)									
		/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
Jordanian Arabic (JA)	c	676	***479***	614	***519***	509	***668***	485	***622***
	k	0.628	0.773	0.662	0.661	0.526	0.389	0.589	0.406
Kuwaiti Arabic (KA)	c	665	764	***513***	595	425	624	***661***	557
	k	0.657	0.614	0.726	0.650	0.600	0.431	0.513	0.506
Moroccan Arabic (MA)	c	817	1010	185	660	370	542	75	407
	k	0.555	0.451	0.926	0.628	0.691	0.593	0.937	0.648
Yemeni Arabic (MA)	c	874	758	***322***	***473***	566	647	***797***	***524***
	k	0.515	0.591	0.833	0.720	0.448	0.389	0.423	0.547
mean (JA, KA, MA and YA)	c	754	719	***396***	559	445	587	***450***	452
	k	0.592	0.618	0.796	0.667	0.595	0.479	0.662	0.516
mean c and k values for MSA (Yeou 1997)									
Moroccan speakers		/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
	c	***623***	936	741	875	***678***	839	681	778
	k	0.66	0.48	0.56	0.46	0.37	0.31	0.35	0.22
c and k values for Cairene Arabic (Sussman et al 1993)									
			/d/				/dˤ/		
Speaker 1	c		1278				954		
	k		0.267				0.153		
Speaker 2	c		1286				839		
	k		0.228				0.319		
Speaker 3	c		1356				1005		
	k		0.240				0.155		
mean	c		1307				933		
	k		0.25				0.21		
mean c and k values (this study)									
		/t/	/d/	/s/	/ð/	/tˤ/	/dˤ/	/sˤ/	/ðˤ/
Libyan Arabic	c	588	963	578		466	644	443	
	k	0.71	0.47	0.68		0.56	0.46	0.63	

Appendix 7b

The order of LE slope and y-intercept in different Arabic dialects

Number 1 represents the highest slope and number 4 the lowest.(this applies to both plain and emphatic contexts									
Modern Standard Arabic (MSA) (Embarki et al 2007)									
		plain				emphatic			
order		1	2	3	4	1	2	3	4
JA speakers	k	/ð/ 0.851	/t/ 0.847	/s/ 0.772	/d/ 0.751	/sˤ/ 0.664	/ðˤ/ 0.552	/dˤ/ 0.540	/tˤ/ 0.460
KA speakers	k	/s/ 0.840	/ð/ 0.739	/t/ 0.666	/d/ 0.653	/sˤ/ 0.788	/tˤ/ 0.515	/dˤ/ 0.471	/ðˤ/ 0.442
MA speakers	k	/s/ 0.822	/t/ 0.787	/ð/ 0.756	/d/ 0.685	/sˤ/ 0.792	/tˤ/ 0.760	/dˤ/ 0.646	/ðˤ/ 0.610
YA speakers	k	/t/ 0.795	/s/ 0.772	/d/ 0.745	/ð/ 0.722	/sˤ/ 0.751	/dˤ/0.541	/ðˤ/ 0.490	/tˤ/ 0.426
mean for all speakers	k	/s/ 0.796	/ð/ 0.667	/d/ 0.618	/t/ 0.592	/sˤ/ 0.662	/tˤ/ 0.595	/ðˤ/ 0.516	/dˤ/ 0.479
Four Arabic dialects (Embarki et al 2007)									
JA	k	/d/ 0.773	/s/ 0.662	/ð/ 0.661	/t/ 0.628	/sˤ/ 0.589	/tˤ/ 0.526	/ðˤ/ 0.406	/dˤ/ 0.389
KA	k	/s/ 0.726	/t/ 0.657	/ð/ 0.650	/d/ 0.614	/tˤ/ 0.600	/sˤ/ 0.513	/ðˤ/ 0.506	/dˤ/ 0.431
MA	k	/s/ 0.926	/ð/ 0.628	/t/ 0.555	/d/ 0.451	/sˤ/ 0.937	/tˤ/ 0.691	/ðˤ/ 0.648	/dˤ/ 0.593
YA	k	/s/ 0.833	/ð/ 0.720	/d/ 0.591	/t/ 0.515	/ðˤ/ 0.547	/tˤ/ 0.448	/sˤ/ 0.423	/dˤ/ 0.389
mean (JA, KA, MA and YA)	k	/s/ 0.796	/ð/ 0.667	/d/ 0.618	/t/ 0.592	/sˤ/ 0.662	/tˤ/ 0.595	/ðˤ/ 0.516	/dˤ/ 0.479
Modern Standard Arabic (MSA) (Yeou 1997)									
Moroccan speakers	k	/t/ 0.66	/s/ 0.56	/d/ 0.48	/ð/ 0.46	/tˤ/ 0.37	/sˤ/ 0.35	/dˤ/ 0.31	/ðˤ/ 0.22
Libyan Arabic (this study)									
LA	k	/t/ 0.71	/s/ 0.68	/d/ 0.47		/sˤ/ 0.63	/tˤ/ 0.56	/dˤ/ 0.46	

Appendix 8

VOT for /t/ and /tˁ/ in different Arabic dialects

the current study

V	/i:/		/ɪ/		/e:/		/o:/		/ʊ/		/u:/		/ɛ/		/æ:/	
	t	tˁ	t	tˁ	t	tˁ	t	tˁ	t	tˁ	t	tˁ	t	tˁ	t	tˁ
Mean	51	21	35	20	35	17	32	15	35	18	33	19	30	17	30	16

Overall mean VOT: /t/ = 35 ms and /tˁ/ = 18 ms

Ghazali (1977)

VOT is 30 ms for /t/ and 10 or 15 ms for /tˁ/

Al-Nuzaili (1993) for one speaker of Yemeni Arabic

	/i:/		/ɪ/					/ʊ/		/u:/		/a/		/a:/	
	t	tˁ	t	tˁ				t	tˁ	t	tˁ	t	tˁ	t	tˁ
Mean	50	9.17	37.5	9.5				33.3	10	41.67	11.67	21.67	10.8	22	8.3

VOT is 15 to 55 for /t/and -30 to 25 for /tˁ/

Bukshaisha (1985) for two male speaker of Qatari Arabic

VOT for /tˁ/ ranged from 0 to 15 ms while it was from 30 to 50 ms for /t/

Kriba (2004) for one speaker of Libyan Arabic

	/i:/										/u:/				/a:/	
	t	tˁ									t	tˁ			t	tˁ
	50	43.6									51	30			30	24.6

VOT is 44 ms for /t/ and 33 ms for /ṭ/

Ahmed (1984) for Sudanese Arabic

VOT is 30 to 70 ms for the plain /t/ and 40 to 90 for the emphatic /tˁ/.

Khattab et al (2006), five male speakers of Jordanian Arabic

VOT is 37 ms and 18 ms for /t/ and /tˁ/ respectively

Heselwood (1996) for four Iraqi speakers

VOT is 31 ms and 16 for /t/ and /tˁ/ respectively

Heselwood (1996) for four Egyptian speakers

VOT is 33 ms for /t/ and 35 ms for /tˁ/

Shaheen (1979) for Egyptian Arabic

slight aspiration for both /t/ and /tˁ/

Rifaat (2003) for Egyptian Arabic

slight aspiration for both /t/ and /tˁ/

Zeroual (1999) for Moroccan Arabic

VOT is 63 and 24 for /t/ and /tˁ/ respectively

Al-Ani (1970) for Iraqi and Jordanian speakers

aspirated /t/ and unaspiarted /tˁ/

Giannini and Pettorino (1982) for Iraqi Arabic

aspirated /t/ and unaspiarted /tˁ/

Odisho (1973) for Iraqi Arabic

aspirated /t/ and unaspiarted /tˁ/

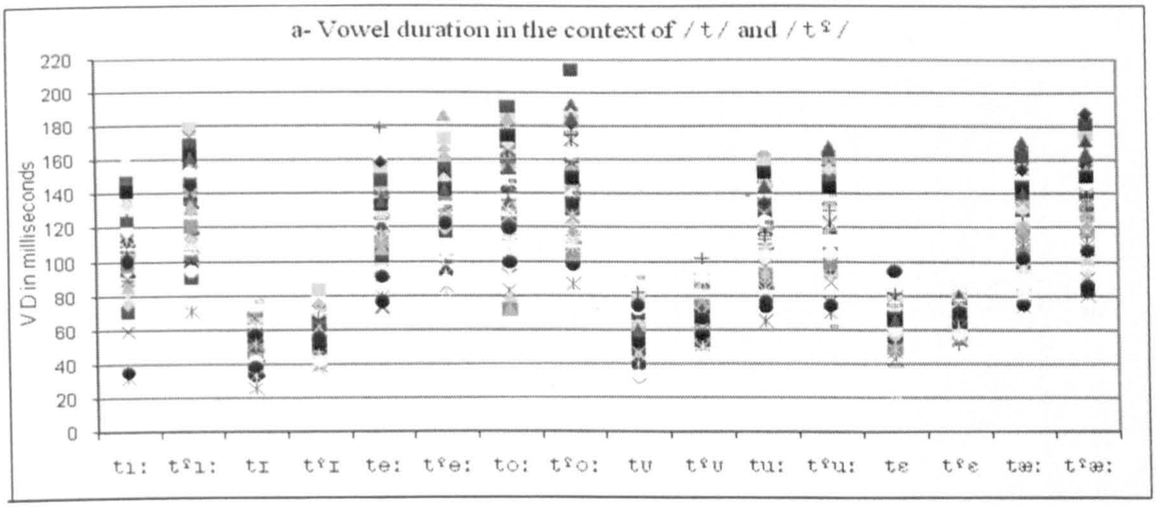
Yeni-komshian et al (1977) for eight speakers of Lebanese Arabic

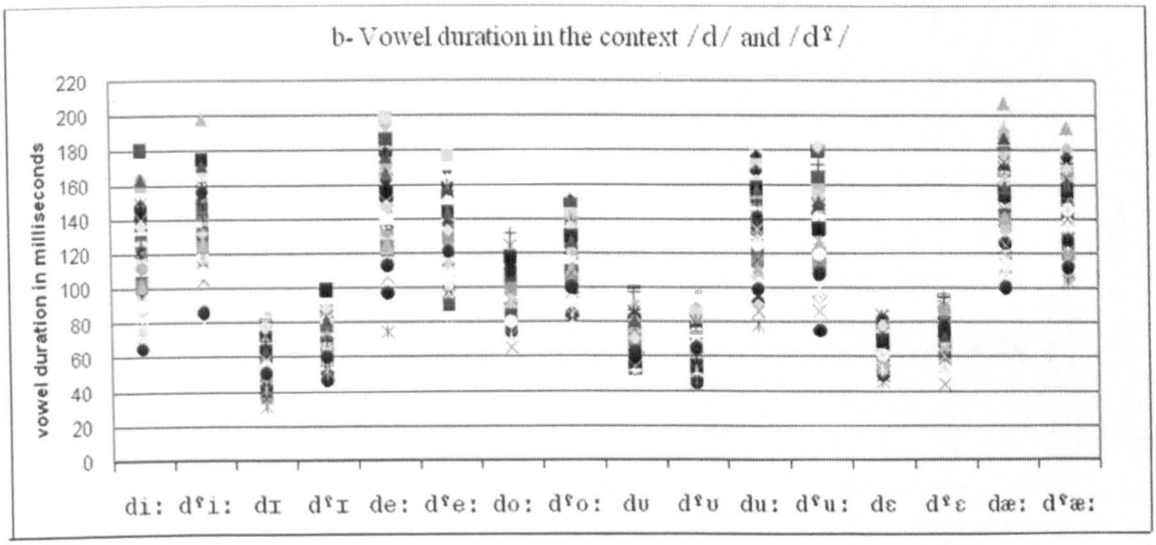
both /t/ and /tˁ/ can be unaspirated or slightly aspirated with /tˁ/ having the lowest values

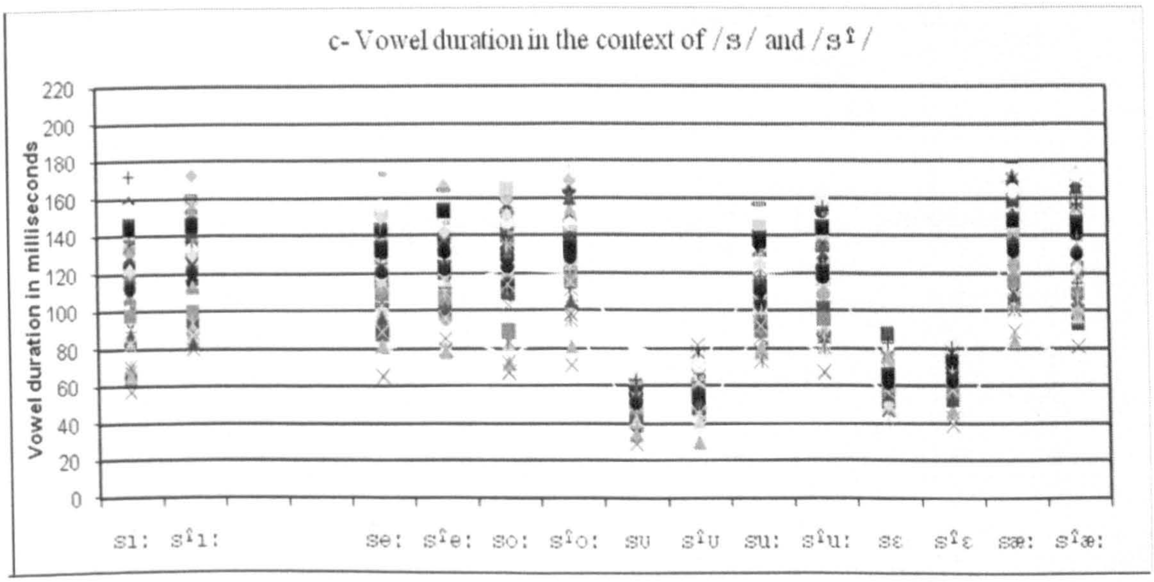
	/a/		/u/		/i/										
	/t/	/tˁ/	/t/	/tˁ/	/t/	/tˁ/									
	20	15	25	20	30	35									

Appendix 9

Vowel duration distribution in plain and emphatic contexts







Appendix 10a

Glossary of the recorded words used in the acoustic analysis

1- The vocalic context of /i:/

entry	word category	meaning	Arabic script
/ti:n/	N.	fig	تين
/tˤi:n/	N.	mud	طين
/di:k/	N.	cock	ديك
/dˤi:g/	N.	narrowness	ضيق
/si:d/	N.	master, father	سيد
/sˤi:d/	V. imp.	hunt	صيد

2- The vocalic context of /ɪ/

entry	word category	meaning	Arabic script
/tɪl/	V. imp.	pull	تِل
/tˤɪl/	V. imp.	pay a visit	طِل
/dɪb/	V. imp.	walk slowly	دِب
/dˤɪd/	Prep.	against	ضِد

3- The vocalic context of /e:/

entry	word category	meaning	Arabic script
/te:s/	N.	a male goat	تيس
/tˤe:ʃ/	N.	indifference	طيش
/de:l/	N.	tale	ديل
/dˤe:f/	N.	guest	ضيف
/se:f/	N.	sword	سيف
/sˤe:f/	N.	summer	صيف

4- The vocalic context of /o:/

entry	word category	meaning	Arabic script
/to:r/	N.	bull	تُور
/tˤo:r/	N.	level	طُور
/do:xa/	N.	dizziness	دُوخه
/dˤo:ga/	N.	something to taste	ضُوقه
/so:m/	N.	price	سُوم
/sˤo:m/	N.	fasting	صُوم

5- The vocalic context of /ʊ/

entry	word category	meaning	Arabic script
/tʊn/	N.	tuna	تُن
/tˤʊn/	N.	a measuring unit	طُن
/dʊl/	N.	scorn	ذُل
/dˤʊm/	V. imp.	hug	ضُم
/sʊl/	N.	tuberculosis	سُل
/sˤʊl/	N.	a type of snake	صُل

6- The vocalic context of /u:/

entry	word category	meaning	Arabic script
/tu:b/	V. imp.	repent	تُوب
/tˤu:b/	N.	bricks	طُوب
/du:d/	N. pl.	worm	دُود
/dˤu:g/	V. imp.	taste	ضُوق
/su:s/	N. pl.	moth	سُوس
/sˤu:f/	N.	wool	صُوف

7- The vocalic context of /ɛ/

entry	word category	meaning	Arabic script
/tɛl/	N.	a metal bar	تَل
/tˤɛl/	V. past	pay a visit	طَل
/dɛb/	V. past	walk	دَب
/dˤɛb/	N.	lizard	ضَب
/sɛf/	V. past	remove dust	سَف
/sˤɛf/	N.	queue, row	صَف

8- The vocalic context of /æ:/

entry	word category	meaning	Arabic script
/tæ:b/	V. past	repent	تَاب
/tˤæ:b/	V. past	cook	طَاب
/dæ:l/	Adj.	guiding	دَال
/dˤæ:l/	Adj.	misleading	ضَال
/sæ:d/	Adj.	enough	سَاد
/sˤæ:d/	V. past	hunt	صَاد

Appendix 10b
The order of recording of the target words

no	entry	no	entry	no	entry	no	entry
1	/ti:n/	13	/tˤæ:b/	25	/dˤʊm/	37	/tˤi:n/
2	/tæ:b/	14	/sʊl/	26	/to:r/	38	/dˤe:f/
3	/du:d/	15	/dɛb/	27	/tˤe:ʃ/	39	/sˤi:d/
4	/sˤʊl/	16	/tˤʊn/	28	/dæ:l/	40	/sæ:d/
5	/tɛl/	17	/dˤɛb/	29	/dˤo:ga/	41	/sˤæ:d/
6	/tˤu:b/	18	/dˤu:g/	30	/tʊn/	42	/si:d/
7	/tˤɛl/	19	/so:m/	31	/dˤæ:l/	43	/sˤu:f/
8	/tu:b/	20	/tˤo:r/	32	/te:s/	44	/sɛf/
9	/tɪl/	21	/dɪb/	33	/su:s/	45	/se:f/
10	/dˤi:g/	22	/dˤɪd/	34	/sˤe:f/	46	/sˤɛf/
11	/di:k/	23	/dʊl/	35	/sˤo:m/		
12	/tˤɪl/	24	/de:l/	36	/do:xa/		

Appendix 11

Reliability checking for 10% of the formant frequency measurements

			first repetition											
			second measurement for checking reliability						first measurement					
subject	token	number	F1 onset	F2 onset	F3 onset	F1 mid	F2 mid	F3 mid	F1 onset	F2 onset	F3 onset	F1 mid	F2 mid	F3 mid
1	tˤɪ	12	452	1196	2776	499	1209	2681	458	1212	2754	497	1207	2694
1	te:	32	387	1992	2811	433	2059	2647	387	1992	2799	428	2083	2673
1	tæ:	2	506	1672	2630	595	1580	2664	515	1671	2637	599	1596	2666
1	si:	42	295	2133	2642	305	2220	2714	295	2140	2650	307	2218	2758
1	dˤɪ	22	406	1212	2743	436	1164	2872	403	1247	2718	433	1145	2853
2	to:	26	435	1402	2481	494	1166	2440	439	1419	2579	502	1204	2485
2	tˤʊ	16	427	920	2460	506	1137	2684	435	939	2448	503	1120	2659
2	tˤu:	6	421	970	2631	345	998	2634	417	962	2567	349	996	2624
2	sˤɛ	46	545	1182	2366	593	1204	2356	547	1179	2368	593	1205	2352
2	do:	36	389	1654	2342	413	1238	2355	389	1663	2343	405	1242	2362
3	tˤo:	20	487	981	2510	514	1090	2453	487	967	2516	511	1086	2442
3	tʊ	30	391	1355	2340	439	1276	2389	405	1337	2205	438	1281	2381
3	sæ:	40	461	1552	2631	577	1524	2614	466	1576	2642	582	1543	2641
3	dˤi:	10	347	1469	2657	337	1981	2677	346	1426	2654	338	1988	2679
4	to:	26	470	1415	2520	522	1158	2571	468	1421	2512	515	1168	2553
4	tˤʊ	16	429	1118	2408	445	1163	2569	429	1128	2349	442	1132	2544
4	tˤu:	6	420	1131	2776	391	830	2824	427	1138	2842	406	884	2901
4	sˤɛ	46	500	1287	2389	541	1215	2405	504	1292	2376	541	1221	2427
4	do:	36	418	1572	2605	507	1351	2554	422	1574	2671	498	1382	2611
5	tˤo:	20	476	944	2422	517	982	2476	470	963	2460	511	972	2462
5	tʊ	30	408	1250	2456	430	1238	2452	408	1250	2456	430	1234	2443
5	sæ:	40	483	1513	2521	576	1488	2503	485	1507	2521	575	1490	2502
5	dˤi:	10	385	1517	2738	394	1924	2803	381	1540	2748	384	1892	2770
6	sˤe:	34	453	1593	2760	477	1907	2679	453	1596	2781	478	1887	2764

6	sʊ	14	434	1669	2792	460	1471	2780	431	1676	2639	464	1474	2776
6	sˤʊ	4	485	1243	2753	520	1193	2701	482	1240	2857	519	1213	2794
6	sɛ	44	508	1673	2897	568	1577	2838	502	1645	2846	544	1556	2828
6	de:	24	370	1993	2817	492	2005	2892	378	1916	2839	481	1857	2770
7	tɪ	9	369	1716	2540	416	1663	2485	378	1681	2449	417	1658	2447
7	sˤi:	39	309	1735	2430	271	2020	2373	312	1758	2429	276	2009	2373
7	so:	19	404	1152	2389	446	945	2369	409	1125	2388	452	966	2383
7	dˤo:	29	424	1034	2799	456	986	2614	422	1123	2782	456	996	2635
8	tˤæ:	13	579	1108	2724	600	1130	2533	580	1108	2719	600	1131	2526
8	su:	33	392	1534	2699	386	1248	2655	393	1538	2698	389	1263	2658
8	sˤu:	43	420	1118	2900	422	959	2839	423	1076	2908	422	975	2841
8	dʊ	23	383	1550	2792	421	1411	2840	335	1618	2441	371	1340	2433
8	du:	3	368	1643	2633	354	1000	2485	367	1621	2609	359	1019	2491
9	tˤi:	37	371	1853	2667	388	2268	2656	371	1886	2669	386	2268	2656
9	tˤe:	27	385	1781	2759	423	1876	2792	388	1738	2798	417	1830	2825
9	tˤɛ	7	510	1272	2909	520	1223	3001	513	1271	2939	520	1215	2926
9	dˤɛ	17	465	1413	2895	514	1264	2905	462	1378	2852	508	1238	2913
10	ti:	1	368	2211	2744	457	2260	2630	368	2214	2751	458	2259	2601
10	te:	32	376	1982	2730	465	2064	2725	376	1964	2699	461	2050	2685
10	si:	42	333	2171	2988	338	2375	3086	333	2199	2988	335	2370	3134
10	di:	11	329	2209	2867	325	2225	2849	335	2186	2846	322	2235	2836
10	dˤɪ	22	476	1258	2560	500	1276	2566	474	1227	2516	488	1254	2573
11	to:	26	460	1237	2488	548	1008	2402	459	1234	2497	540	1008	2402
11	tˤʊ	16	505	1040	2582	505	980	2552	507	1021	2588	504	978	2545
11	tˤu:	6	393	949	2624	434	846	2620	393	943	2622	434	848	2618
11	sˤɛ	46	569	1084	2805	622	1009	2799	579	1091	2801	620	1011	2802
11	do:	36	438	1485	2539	486	1122	2602	427	1512	2551	492	1125	2643
12	tˤo:	20	441	1035	2748	471	951	2716	442	1029	2742	471	949	2719

12	tʊ	30	421	1299	2531	433	1332	2533	425	1299	2537	433	1328	2512
12	sæ:	40	427	1847	2776	562	1703	2660	429	1833	2767	561	1690	2637
12	dˤi:	10	421	1647	2534	386	1895	2734	424	1625	2459	381	1857	2682
13	sˤe:	34	474	1499	2865	503	1837	2759	479	1503	2835	505	1847	2802
13	sʊ	14	391	1787	2763	369	1698	2632	393	1760	2745	374	1701	2637
13	sˤʊ	4	422	1293	2921	498	1318	2832	421	1282	2905	493	1305	2806
13	sɛ	44	496	1589	2767	593	1452	2756	505	1587	2756	590	1467	2755
13	de:	24	389	2055	2797	491	1986	2759	388	2071	2756	489	1978	2727
14	tu:	8	394	1053	2646	444	1018	2905	398	1036	2713	443	1019	2906
14	dˤe:	38	431	1278	2288	482	1713	2389	434	1302	2324	480	1687	2380
14	dˤu:	18	373	727	2405	370	748	2323	366	733	2441	370	749	2326
14	dæ:	28	438	1905	2679	599	1815	2630	438	1906	2641	597	1805	2793
15	tˤɪ	12	466	1242	2462	498	1378	2481	463	1241	2455	492	1359	2473
15	te:	32	320	1935	2775	519	1907	2527	319	1922	2732	515	1918	2578
15	tæ:	2	451	1794	2657	656	1488	2199	453	1794	2666	657	1488	2198
15	si:	42	299	2107	2752	329	2091	2645	297	2065	2632	326	2093	2624
15	dˤɪ	22	438	1237	2626	491	1111	2530	443	1245	2626	491	1124	2534
16	to:	26	415	1131	2647	451	1013	2546	414	1071	2622	447	1041	2618
16	tˤʊ	16	450	968	2527	470	1071	2538	449	966	2513	567	1073	2540
16	tˤu:	6	367	752	2760	374	856	2606	365	757	2751	377	856	2609
16	sˤɛ	46	588	1123	2399	656	1159	2297	578	1122	2396	655	1151	2281
16	do:	36	390	1534	2287	441	1078	2350	404	1401	2299	441	1079	2351
17	tˤo:	20	500	987	2677	509	999	2453	503	978	2673	509	995	2472
17	tʊ	30	422	1635	2495	401	1536	2453	423	1637	2498	399	1531	2456
17	sæ:	40	486	1572	2470	559	1557	2581	490	1566	2491	559	1557	2591
17	dˤi:	10	335	1830	2650	329	2086	2869	337	1830	2653	327	2086	2867
18	sˤe:	34	418	1531	2572	483	1824	2534	417	1532	2571	483	1844	2561
18	sʊ	14	340	1365	2373	404	1204	2343	344	1355	2376	402	1207	2335

18	sˤʊ	4	438	1005	2588	458	1020	2551	441	1001	2582	459	1015	2568
18	sɛ	44	471	1479	2544	504	1187	2462	477	1477	2547	505	1183	2469
18	de:	24	334	1818	2493	488	1779	2662	336	1823	2494	488	1763	2651
19	tu:	8	363	1268	2401	383	842	2445	368	1269	2357	387	846	2439
19	dˤe:	38	411	1109	2639	441	1508	2572	408	1059	2583	442	1477	2507
19	dˤu:	18	360	889	2551	363	834	2462	353	885	2563	360	835	2504
19	dæ:	28	380	1590	2433	558	1549	2340	374	1563	2426	550	1554	2355
20	tˤɪ	12	383	1492	2817	424	1404	2680	379	1455	2773	426	1388	2716
20	te:	32	358	1845	2792	422	1823	2671	315	1855	2822	413	1825	2678
20	tæ:	2	418	1661	2647	631	1534	2217	424	1667	2682	634	1537	2292
20	si:	42	322	1852	2582	325	1926	2648	323	1871	2509	323	1920	2638
20	dˤɪ	22	397	1236	2512	431	1189	2912	403	1206	2629	431	1180	2916
second repetition														
			second measurement for checking reliability						**first measurement**					
subject	token	number	F1 onset	F2 onset	F3 onset	F1 mid	F2 mid	F3 mid	F1 onset	F2 onset	F3 onset	F1 mid	F2 mid	F3 mid
1	to:	26	413	1232	2630	450	946	2622	413	1188	2663	459	984	2612
1	tˤʊ	16	438	962	2802	483	921	2920	357	942	2802	425	715	2942
1	tˤu:	6	357	757	2937	401	643	2978	351	754	2879	398	644	2957
1	sˤɛ	46	465	1170	2665	570	1072	2669	470	1168	2692	579	1058	2668
1	do:	36	427	1534	2722	510	1078	2690	431	1649	2666	511	1089	2683
2	tˤo:	20	479	912	2322	537	1033	2409	473	899	2420	534	1036	2394
2	tʊ	30	434	1461	2421	487	1424	2462	434	1451	2417	483	1423	2463
2	sæ:	40	534	1673	2618	602	1608	2466	531	1673	2575	595	1624	2483
2	dˤi:	10	338	1559	2760	355	2020	2786	338	1569	3352	357	2026	2799
3	se:	45	421	1824	2556	518	1905	2584	418	1750	2559	523	1923	2599
3	sˤo:	35	459	1092	2518	550	1039	2447	456	1105	2508	552	1087	2442
3	tɛ	5	549	1565	2614	559	1549	2660	553	1559	2149	558	1546	2310
3	dɛ	15	454	1650	2727	534	1558	2647	451	1644	2708	527	1570	2631

3	dˤʊ	25	426	1034	2550	470	825	2490	423	1335	2324	464	983	2413
4	tɪ	9	417	1849	2630	436	1853	2706	407	1837	2676	433	1855	2673
4	sˤiː	39	393	1832	2735	382	1840	2596	394	1833	2728	382	1857	2593
4	soː	19	460	1547	2495	486	1127	2393	459	1526	2551	490	1166	2416
4	dˤoː	29	428	1373	2824	509	1348	2802	424	1381	2860	510	1359	2816
5	sˤeː	34	461	1308	2582	470	1582	2534	456	1304	2566	472	1541	2542
5	sʊ	14	423	1276	2405	424	1347	2401	423	1293	2428	425	1345	2403
5	sˤʊ	4	446	993	2407	445	982	2349	445	993	2402	448	983	2345
5	sɛ	44	529	1326	2390	545	1320	2392	526	1324	2388	548	1314	2407
5	deː	24	411	1873	2599	456	1937	2679	406	1817	2586	452	1954	2658
6	toː	26	420	1535	2647	518	1177	2663	424	1529	2581	514	1137	2650
6	tˤʊ	16	471	1236	2737	493	1148	2756	476	1216	2739	493	1148	2754
6	tˤuː	6	385	1090	2701	373	996	2739	384	1079	2708	371	997	2737
6	sˤɛ	46	517	1408	2785	606	1314	2920	518	1368	2784	606	1288	2950
7	tˤoː	20	486	966	2750	486	935	2623	486	969	2744	486	949	2624
7	tʊ	30	405	1073	2470	422	1074	2392	405	1107	2423	418	1081	2390
7	sæː	40	444	1487	2517	525	1470	2528	443	1524	2544	526	1498	2558
7	dˤiː	10	343	1450	2588	319	1950	2498	345	1463	2577	320	1942	2482
8	sˤeː	34	405	1625	2822	446	1853	2739	404	1623	2817	451	1863	2755
8	sʊ	14	381	1302	2684	409	1407	2906	391	1299	2672	409	1408	2908
8	sˤʊ	4	424	1063	2767	439	987	2777	426	1045	2779	440	987	2787
8	sɛ	44	475	1525	2811	567	1384	2695	473	1518	2816	568	1381	2698
8	deː	24	358	1969	2679	422	2140	2860	361	2023	2744	421	2185	2884
9	tuː	8	325	1372	2566	351	1029	2589	335	1355	2550	350	1029	2591
9	dˤeː	38	388	1357	2751	485	1647	2728	391	1333	2681	482	1630	2705
9	dˤuː	18	318	1405	2654	372	986	2595	320	1398	2652	363	1050	2596
9	dæː	28	411	1770	2756	531	1599	2746	414	1749	2756	529	1597	2718
10	tæː	2	486	1841	2679	637	1808	2583	483	1831	2683	635	1795	2588

10	tˤæ:	13	557	1274	2592	600	1237	2527	557	1273	2583	597	1231	2469
10	su:	33	374	1293	2663	366	986	2389	374	1295	2643	374	987	2442
10	sˤu:	43	390	1115	2776	427	1024	2701	394	1125	2770	427	1032	2702
10	dʊ	23	411	1760	2555	443	1679	2472	416	1739	2549	454	1668	2516
11	tˤi:	37	373	1535	2566	344	2136	2597	367	1492	2487	350	2128	2530
11	tˤe:	27	431	1395	2614	504	1647	2506	430	1395	2561	496	1644	2498
11	tˤɛ	7	562	1131	2776	592	1130	2823	555	1119	2810	594	1127	2820
11	dˤɛ	17	503	1110	2792	567	1100	2850	505	1093	2736	567	1100	2778
12	ti:	1	332	2348	2990	364	2343	2950	333	2357	2961	363	2343	2939
12	sˤæ:	41	567	1310	2888	626	1261	2759	549	1278	2835	629	1214	2746
12	di:	11	341	2172	2901	338	2211	2865	348	2136	2922	333	2196	2887
12	dɪ	21	381	1900	2848	398	1915	2810	380	1891	2829	397	1903	2780
12	dˤæ:	31	443	1229	2869	565	1021	2822	446	1231	2863	564	1023	2855
13	tɛ	5	480	1775	2737	506	1786	2737	481	1768	2729	504	1779	2730
13	se:	45	405	1985	2743	477	1908	2617	409	1987	2738	476	1912	2628
13	sˤo:	35	470	1147	2838	536	927	2769	463	1151	2829	532	918	2771
13	dˤʊ	25	426	825	3070	440	823	3034	428	816	3050	437	826	3024
13	dɛ	15	421	1824	2743	527	1693	2712	420	1808	2833	526	1699	2713
14	tɪ	9	431	1934	2668	431	1911	2550	431	1925	2674	432	1917	2523
14	sˤi:	39	357	2276	2678	373	2260	2687	357	2268	2669	369	2218	2665
14	so:	19	534	1583	2343	535	1224	2284	534	1558	2345	527	1229	2290
14	dˤo:	29	462	962	2536	491	965	2450	464	960	2547	491	965	2456
15	tˤæ:	13	550	1208	2437	700	1243	2445	550	1210	2439	691	1246	2452
15	su:	33	341	1434	2421	357	1048	2347	336	1457	2410	357	1051	2351
15	sˤu:	43	357	1083	2518	377	908	2481	356	1090	2522	374	968	2516
15	dʊ	23	313	1566	2341	437	1357	2364	315	1559	2301	435	1364	2364
15	du:	3	316	1723	2550	405	825	2405	316	1705	2453	390	822	2358
16	tˤi:	37	313	1313	2592	350	2049	2516	314	1314	2594	349	2056	2518

16	tˤe:	27	385	1619	2671	459	2071	2673	354	1614	2689	323	2077	2668
16	tˤɛ	7	551	1050	2357	693	1212	2346	554	1058	2345	693	1209	2347
16	dˤɛ	17	580	1115	2656	679	1183	2469	572	1149	2715	673	1174	2539
17	ti:	1	342	1986	2740	353	2113	2702	339	1992	2734	353	2116	2701
17	sˤæ:	41	602	1196	2808	659	1255	2820	604	1202	2822	660	1255	2821
17	di:	11	329	1940	2776	340	2002	2824	327	1931	2767	339	1994	2809
17	dˤæ:	31	518	1180	2760	641	1258	2808	522	1173	2894	639	1256	2804
18	tɛ	5	469	1636	2722	520	1783	2679	470	1637	2722	517	1798	2696
18	se:	45	409	1662	2518	438	1953	2528	406	1663	2520	444	1951	2523
18	sˤo:	35	481	1046	2642	487	936	2617	482	1045	2643	490	942	2631
18	dˤʊ	25	439	825	2651	446	840	2599	437	835	2585	446	840	2601
18	dɛ	15	397	1551	2534	549	1542	2624	397	1551	2515	542	1558	2625
19	tɪ	9	389	1649	2485	425	1600	2476	389	1649	2487	422	1604	2467
19	sˤi:	39	317	1431	2546	329	1812	2454	315	1433	2552	329	1814	2456
19	so:	19	406	1212	2550	438	936	2437	401	1115	2494	440	935	2433
19	dˤo:	29	411	867	2512	457	900	2478	413	859	2494	454	898	2480
20	tˤæ:	13	520	1029	2673	585	1290	2510	519	1025	2668	582	1282	2506
20	sˤe:	34	381	1518	2421	422	1687	2582	383	1526	2437	420	1694	2586
20	sɛ	44	438	1582	2614	488	1530	2592	441	1600	2629	490	1528	2583
20	de:	24	341	1680	2453	406	1769	2582	347	1676	2472	407	1764	2560
20	du:	3	313	1616	2498	338	929	2413	313	1616	2486	337	948	2420
third repetition														
			second measurement for checking reliability						first measurement					
subject	token	number	F1 onset	F2 onset	F3 onset	F1 mid	F2 mid	F3 mid	F1 onset	F2 onset	F3 onset	F1 mid	F2 mid	F3 mid
1	tu:	8	331	1445	2712	391	893	2647	332	1430	2719	391	897	2624
1	sˤi:	39	354	1647	2695	352	2195	2647	356	1628	2699	350	2192	2645
1	so:	19	407	1325	2695	551	1099	2566	407	1326	2688	547	1114	2582

1	dˤo:	29	422	1122	2824	503	1034	2874	424	1117	2806	498	1032	2878
2	su:	33	389	1442	2776	373	1276	2743	383	1433	2789	368	1284	2757
2	sˤu:	43	389	1157	2988	357	1195	2841	389	1176	3014	363	1187	2832
2	dʊ	23	374	1582	2518	390	1422	2453	374	1584	2633	393	1436	2471
2	du:	3	344	1696	2260	378	1034	2485	344	1688	2264	380	1007	2480
3	tˤɛ	7	643	1212	2595	630	1257	2632	640	1213	2597	628	1258	2632
3	tˤi:	37	399	1477	2732	405	1984	2669	401	1492	2743	406	1983	2679
3	dˤɛ	17	499	1196	2692	577	1206	2665	496	1216	2685	577	1205	2666
3	tˤe:	27	490	1205	2645	515	1789	2634	493	1207	2645	517	1786	2633
4	tˤɪ	12	472	1426	2624	499	1696	2690	472	1444	2728	501	1708	2685
4	te:	32	441	1851	2755	465	1825	2575	439	1867	2775	465	1827	2576
4	tæ:	2	493	1658	2610	595	1569	2785	494	1658	2613	595	1571	2777
4	sˤi:	42	352	2022	2510	362	2055	2553	352	2022	2509	360	2054	2519
4	dˤɪ	22	416	1387	2852	470	1374	2866	416	1345	2801	468	1364	2860
5	to:	26	434	1254	2443	481	1004	2410	435	1259	2448	480	1004	2416
5	tˤʊ	16	436	878	2359	438	887	2353	435	879	2353	446	883	2363
5	tˤu:	6	385	999	2615	374	890	2598	383	1006	2604	372	894	2577
5	sˤæ:	46	567	1187	2437	632	1196	2329	559	1172	2435	628	1186	2299
5	do:	36	428	1306	2516	454	1186	2534	429	1299	2507	458	1186	2597
6	tˤo:	20	459	1160	2868	509	1065	2788	459	1157	2858	507	1058	2791
6	tʊ	30	422	1301	2574	440	1226	2608	423	1309	2574	440	1226	2608
6	sæ:	40	460	1923	2913	622	1630	2950	460	1912	2926	612	1602	2965
6	dˤi:	10	370	1695	2856	346	2075	2886	370	1697	2822	345	2052	2856
7	sˤe:	34	407	1311	2592	423	1551	2466	406	1329	2579	422	1549	2463
7	sʊ	14	424	1276	2437	438	1228	2421	423	1270	2444	437	1234	2418
7	sˤʊ	4	450	1034	2760	486	1013	2724	452	1050	2757	484	1002	2725
7	sɛ	44	461	1460	2523	477	1421	2510	452	1448	2519	478	1420	2513
7	de:	24	341	1760	2456	422	1744	2424	338	1767	2453	423	1751	2423

8	tu:	8	354	1510	2544	379	1060	2588	355	1493	2548	379	1056	2582
8	dˤe:	38	425	1357	2804	433	1782	2824	425	1366	2800	432	1779	2815
8	dˤu:	18	376	1236	2640	373	999	2613	376	1244	2592	377	999	2592
8	dæ:	28	425	1813	2830	602	1534	2843	423	1805	2831	608	1525	2836
9	tˤɪ	12	427	1196	2840	418	1225	2858	430	1128	2841	420	992	2839
9	te:	32	367	2066	2868	399	2043	2887	366	2057	2805	395	2042	2803
9	tæ:	2	422	1882	2840	542	1691	2824	419	1871	2840	541	1690	2833
9	si:	42	296	2195	2905	292	2265	2872	297	2176	2894	288	2244	2837
9	dˤɪ	22	422	1391	2921	422	1311	2968	422	1411	2941	422	1311	2968
10	to:	26	486	1389	2518	514	1067	2470	488	1390	2511	508	1091	2453
10	tˤʊ	16	486	1035	2308	529	1116	2315	481	1048	2307	526	1082	2233
10	tˤu:	6	434	1176	2803	456	1013	2557	435	1187	2804	458	1015	2553
10	sˤɛ	46	553	1236	2589	589	1258	2630	550	1235	2592	589	1258	2614
10	do:	36	385	1696	2685	500	1310	2455	382	1716	2693	498	1320	2451
11	tˤo:	20	476	1067	2722	516	984	2626	476	1063	2726	516	986	2620
11	tʊ	30	460	1308	2520	494	1198	2461	463	1309	2511	497	1200	2463
11	sæ:	40	470	1696	2752	644	1486	2809	471	1700	2760	639	1496	2808
11	dˤi:	10	325	1760	2485	341	2221	2848	315	1756	2491	341	2225	2831
12	sˤe:	34	461	1609	2830	461	1733	2755	464	1616	2824	461	1734	2756
12	sʊ	14	407	1491	2543	431	1417	2515	406	1449	2547	431	1426	2511
12	sˤʊ	4	441	1260	2756	456	1090	2717	444	1247	2753	456	1089	2719
12	sɛ	44	486	1646	2784	522	1583	2630	487	1623	2740	513	1573	2649
12	de:	24	354	2002	2808	435	2000	2760	362	1964	2781	430	1885	2702
13	tɪ	9	412	2028	2798	387	1992	2768	414	2027	2803	390	1994	2768
13	sˤi:	39	394	2136	2868	368	2256	2732	396	2132	2868	369	2242	2787
13	so:	19	451	1545	2765	525	1180	2607	454	1541	2764	525	1174	2619
13	dˤo:	29	423	1225	2964	498	1121	2918	416	1256	2944	496	1118	2925
14	tˤæ:	13	545	1212	2647	760	1216	2679	542	1282	2630	753	1221	2587

14	su:	33	381	1515	2646	371	1375	2547	379	1510	2638	371	1372	2546
14	sˤu:	43	396	999	2691	367	905	2610	394	981	2684	363	879	2612
14	dʊ	23	371	1599	2319	399	1228	2335	372	1616	2388	397	1249	2326
14	du:	3	364	1643	2555	379	1244	2437	366	1647	2553	381	1262	2424
15	tˤi:	37	394	1555	2552	352	2143	2442	395	1534	2536	349	2131	2449
15	tˤe:	27	503	1463	2499	476	1654	2386	505	1476	2487	471	1650	2415
15	tˤɛ	7	549	1221	2449	562	1228	2354	550	1219	2448	563	1226	2355
15	dˤɛ	17	497	1236	2513	551	1243	2456	498	1235	2518	549	1243	2454
16	ti:	1	316	2293	2969	318	2437	2937	314	2246	2929	315	2438	2977
16	sˤæ:	41	523	1100	2426	709	1258	2456	532	1106	2435	706	1251	2465
16	di:	11	277	2127	2893	327	2368	2963	273	2127	2884	328	2375	2975
16	dɪ	21	357	1946	2700	416	1896	2664	359	1941	2707	411	1900	2623
16	dˤæ:	31	536	1114	2601	734	1190	2365	539	1117	2597	731	1189	2373
17	tɛ	5	536	1671	2613	568	1683	2655	538	1673	2626	566	1686	2654
17	se:	45	414	1873	2617	450	1905	2620	417	1874	2612	450	1903	2607
17	sˤo:	35	493	1067	2565	487	1002	2340	495	1082	2574	484	1001	2322
17	dˤʊ	25	362	1189	2629	422	1040	2668	366	1181	2621	422	1054	2666
17	dɛ	15	411	1566	2592	496	1525	2589	412	1569	2602	497	1524	2591
18	tɪ	9	367	1840	2696	455	1767	2686	366	1816	2667	465	1764	2665
18	sˤi:	39	309	1889	2566	316	2018	2637	301	1869	2477	316	2019	2640
18	so:	19	405	1371	2574	476	1066	2615	404	1373	2572	477	1069	2636
18	dˤo:	29	409	1083	2505	467	1018	2398	408	1093	2498	470	1016	2391
19	tˤæ:	13	529	948	2515	584	969	2346	531	953	2504	589	974	2356
19	su:	33	309	1389	2428	309	954	2485	306	1404	2424	299	939	2499
19	sˤu:	43	346	803	2533	341	808	2518	348	800	2533	350	805	2556
19	dʊ	23	334	1457	2492	400	1397	2373	338	1463	2504	397	1399	2381
19	du:	3	327	1467	2380	336	998	2392	324	1451	2362	338	1045	2389
20	tˤi:	37	345	1421	2760	431	1855	2595	354	1403	2795	435	1876	2602

20	tˤe:	27	444	1333	2788	465	1659	2755	445	1341	2790	462	1665	2756
20	tˤɛ	7	516	938	2619	565	1136	2512	516	932	2594	566	1135	2515
20	dˤɛ	17	479	1024	2737	540	1173	2648	478	996	2741	536	1148	2636