An Acoustic & Articulatory Analysis of Consonant Sequences across Word Boundaries in Tripolitanian Libyan Arabic

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Dedication

To my late father, Dr Milad Ghummed, may Allah have mercy on him, whose words of advice guide me to this day, and to my mother, Amina Al-Bourgi, for her thoughts and prayers.

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Special thanks to my mother. Her thoughts, encouragement, and continuous prayers have helped me during my studies. I would also like to thank my wife and children for their patience. Special thanks to my true friend and colleague Dr. Raouf Shitaw. His valuable comments and our discussions during our coffee breaks have also assisted in achieving this work. I would also like to thank the ten participants who took part in this study. Their time and patience during the data collection period will always be appreciated.

Abstract

The main goal of this thesis is to provide a description of the articulatory and temporal interaction between stops spanning the word boundary in the four sequence types VC#CV, VC#CCV, VCC#CV, and VCC#CCV in Tripolitanian Libyan Arabic. A general aim of the study is to contribute to the Phonetic description of Libyan Arabic and to provide a better understanding of speech production and the temporal organisation of articulatory gestures. One of the principal objectives of this study is to investigate what effect an increase in the number of stops in a sequence will have on the timing of stop gestures. Furthermore, the study aims to identify the different patterns of gestural coordination and the types of inter-consonantal intervals occurring between stops in the four sequence types. Another aim of the study is to investigate the nature of the resulting inter-consonantal intervals occurring between these stops in order to understand the patterns of epenthesis. Factors affecting gestural coordination such as the order of place of articulation of stops and speech rate are also an objective of this study. Voice assimilation across the word boundary is also investigated in addition to the influence of inter-consonantal intervals on the process.

The study adopts Articulatory Phonology as a theoretical framework to carry out the investigations. The data was collected through recordings of participants' speech and was subjected to EPG and acoustic analysis. Ten native speakers of Tripolitanian Libyan Arabic took part in the acoustic part of the study. Two of the speakers also took part in the EPG part of the study.

Results show that the effect of the number of stops in a sequence on gestural timing is not limited to within syllable-initial and final clusters but also spreads across the word boundary. The timing of syllable-final and syllable-initial stops decreases as a result of the increase in the number of stops across the word boundary. The results also show that the timing of syllable-final clusters is more variable than syllable-initial clusters in across word boundary sequences.

Different sequences types exhibit different degrees of gestural coordination and epenthesis patterns between adjacent stops. Inter-consonantal intervals occurring as a result of lag durations between adjacent stop gestures fall into two types. The first type are typical of transitional excrescent vowels with a mean duration ranging from 14ms-20ms and their voice values exhibit more variation as a result of the voice context in which they occur. Inter-consonantal intervals of the second type are typical of epenthetic vowels with a mean duration ranging from 43ms-51ms and are usually specified as voiced. The patterns of epenthesis also show that Tripolitanian Libyan Arabic belongs to the VC type of languages where sequences of three stops CCC are broken up by epenthesis occurring between C1 and C2 of the sequence.

Statistical tests show a significant effect for order place of articulation on gestural coordination across the word boundary in TLA in the C#C sequence where gestures are more closely coordinated in the coronal-dorsal order. Regressive voice assimilation is more frequent and the voice context of the stops involved plays a major role in determining the direction of voice assimilation spreading. Progressive voice assimilation is limited to the –V+V voice context and whereas regressive assimilation of voicelessness occurs in both. Furthermore, excrescent vowels are found to be transparent to voice assimilation and are dependent on the voicing of the trigger segment. On the other hand, epenthetic vowels block voice assimilation and are more dependent usually specified as voiced.

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TLA	Tripolitanian Libyan Arabic
EPG	Electropalatography
LA	Libyan Arabic
MSA	Modern standard Arabic
WLA	Western Libyan Arabic
SI	syllable-initial
SF	syllable-final
CS	consonant sequence
TT	tongue tip
TB	tongue back
rls	release
#	word boundary
.	syllable boundary
C	consonant
V	vowel
ICI	interconsonantal interval

Chapter 1 Introduction and background

1.1 Introduction

During the process of speech production, different articulators are employed in the production of different speech sounds and the shape of the vocal tract undergoes constant changes during this process. One of the major difficulties in studying speech production is the problem of observing how speakers coordinate various articulatory movements during this speech process.

Speech production involves the movement of different articulators in the vocal tract in order to take up different positions and contacts for the production of different sounds. In isolation, there are three main phases in the production of stops, approach, hold, and release phase. During the hold phase, air pressure builds up behind the closure. At the release of this closure, pressure is released in the form of a burst or transient. This burst, although shorter in duration than the turbulence of fricatives, is the acoustic property of stops. It continues until the pressure behind and in front of the closure equalizes.

This explanation can be applied to speech sounds or phonemes when produced in isolation. However, in continuous speech, where phonemes are joined together to form syllables, and words to form sentences, the process differs. One of the main characteristics of continuous speech is the great variability in the articulatory and acoustic properties of sound segments and that these segments are extremely sensitive to context and also exhibit considerable influence from surrounding segments (Hardcastle *et al.* 2006:1).

When consonants occur in a sequence, their production is affected by coarticulation which is considered to be a fundamental characteristic of continuous speech. The timing of the production of consonants in sequence differs from their production in isolation. The tongue must execute both stops at a very short period of time and as a result the consonants are not discretely articulated. There is a short period of overlapping or simultaneous closure when articulators participate in the production of a sequence of stops and the extent of overlap depends on factors such as phonetic environment and speech rate (Hardcastle & Roach 1979:531).

This process is also known as overlapping or temporal co-occurrence. In the production of speech, each utterance is made up of a combination of gestures. Co-production is the temporal co-occurrence or overlap that takes place in the articulation of two or more gestures.

Continuous speech is made of different gestures that overlap in space and time during the speech process. In the production of stops for example, the approach, hold, and release stage can be considered as a gesture. It is the movement of articulators for a specific intended sound in space and time. Gestures are units of action that can be identified by observing vocal tract articulators as they move in coordination (Browman *et al*. 1989:69). In other words, repeated observations of the process of producing a specific utterance will show a pattern of constrictions being formed and released. Browman *et al.* add that the gestures of a given utterance are organized into larger coordinated structure that is represented in a gestural score. During the production of speech gestures, the shape of the oral tract is constantly changing. At one stage of the production of a given gesture it is completely open whereas at a stage for the production of a different gesture it may be constricted or closed.

1.2 Outline of the study

This thesis is organized as follows: Chapter 1 and Chapter 2 are the literature review chapters. This opening chapter provides an introduction and background to the study, presenting the theoretical framework that has been adopted in this study. It is also devoted to outlining the focus and purpose of the study. The chapter introduces the dialect under investigation in this study, namely Tripolitanian Libyan Arabic, and presents a detailed account of its phonemic inventory and syllabic template. Previous studies conducted on this dialect are also highlighted in addition to relevant studies conducted on gestural coordination of consonants in other languages.

Chapter 2 describes the timing and acoustics of stops. The notion of gesture in Articulatory Phonology is also introduced in addition to the processes of epenthesis and assimilation. The aim of this chapter is to develop the theoretical context essential for discussing and explaining the results of the study. Gestural coordination in stop sequences and the factors that are thought to influence the rate of gestural coordination including syllable position, place of articulation, and speech rate are also introduced. Chapter 2 will also discuss the process of epenthesis and vowel intrusion in stop sequences. The reasons behind epenthesis in stop sequences are covered in addition to the different patterns of epenthesis in stop sequences that are applied by speakers of different languages based on the syllable structure and phonotactics of these languages. The nature of epenthetic vowels is discussed in order to develop an understanding to identify the types of epenthetic vowels applied by speakers in this study.

Chapter 3 is the methodology chapter. In this chapter the main research questions are put forward and then details the methods used in this study to address these. The subjects and methods of data collection are also discussed in depth in this chapter. The two main types of data analysis to be used, electropalatography (henceforth EPG), and acoustics, are introduced in addition to their respective advantages and limitations discussed.

Chapters 4 and 5 present the results of the investigations. Chapter 4 is the EPG data results and chapter 5 is the acoustic data results. The final chapter, chapter 6, discusses the key findings of the study and concludes the thesis. This chapter also identifies the limitations of the study and present suggestions for future research.

1.3 Theoretical framework

This study adopts a gestural approach to speech production as put forward in Articulatory Phonology. According to generative phonology, phonemes can be broken down into smaller constituents using their distinctive features. For example the oral plosive /b/ is represented as a feature matrix [-sonorant, -continuant, +labial, +voice, -nasal]. It is posited that the replacement of any one of these features will result in a different phoneme. Thus, for example if the [+voice] feature is replaced with [-voice] the result will be the oral plosive /p/. In recent years there have been a number of developments in phonological theory one of them being Articulatory Phonology, which describes the process of speech in terms of gestures. This theory suggests that gestures, rather than features, are the basic units of phonological contrast. Browman & Goldstein (1987:1) argue that the multi-dimensional nature of articulation can account for a number of phonological phenomena especially those involving overlapping articulatory gestures. As a result, they choose to represent linguistic structures in terms of coordinated articulatory movements which they call gestures, claiming that these are organized into a gestural score that resembles an autosegmental representation. In their view, gestures are abstract, discrete, and dynamic linguistic units that are invariable across different contexts.

Furthermore, Browman & Goldstein (1988:140) argue that by observing vocal tract activity during the process of speech various stable patterns may be observed such as the formation and release of lip or tongue constrictions. They posit that these characteristic patterns of movements or gestures can form the basis for a phonological description of speech. Using the task dynamics model they claim that individual gestures can be characterized in terms of coordinated patterns of sets of articulators. According to Browman & Goldstein (1992:156), task dynamics has been used to account for coordinated actions involving more than one articulator. In speech, these tasks involve the formation of various constrictions relevant to a particular language. One of the important aspects of task dynamics is the motion of tract variables, which characterizes a dimension of vocal tract constriction, and not the motion of individual articulators that is characterized dynamically. For example, a lip aperture tract variable is affected by the actions of the upper and lower lip in addition to the jaw. They explain that a gesture in Articulatory Phonology is specified using a set of related tract variables so that, for example, in the oral tract, the constriction location and degree are two dimensions of the same constriction and thus considered related tract variables. In Articulatory Phonology utterances are modeled as organized patterns or ‘constellations’ of gestures where gestural units may overlap in time, and these patterns of overlapping gestures can be used to account for different types of phonological variations such as allophonic variations, coarticulation, and speech errors.

But others disagree with the abstract notion of gestures preferring instead to describe speech as complex muscular events which are temporally organized. Mowrey & Pagliuca (1995:56) argue that muscular events differ from gestures as understood in Articulatory Phonology since the latter refer to control structures for the movement of articulators in spatial and temporal terms rather than to muscular events underlying any and all movements. They further note that gestures in Articulatory Phonology are expressed as groups of vocal tract variables which are set to achieve an articulatory task or target and thus refer to an abstract entity which controls physical movement whilst muscular events take place at particular times within utterances synchronically and change in magnitude and timing diachronically (Mowrey & Pagliuca 1995:57). In their opinion, therefore, gestures in articulatory evolution refer to neuromuscular events that are more concrete.

Others authors have viewed gestures as phonetic events rather than abstract phonological units, seeing these as dynamic units, meaning that their state changes in time. Gafos (2002:271) defines gestures as spatio-temporal units that consist of attaining a constriction at a location in the vocal tract. This notion of gestures being considered as concrete articulatory movements has been adopted in recent work by many in their description of processes such as gestural coordination, coarticulation, assimilation, epenthesis and vowel intrusion, and deletion (Byrd & Saltzman 2002; Gafos 2009; Hall 2003). For example, in his description of gestures, Gafos (2002) states that as a gesture unfolds, a set of landmarks may be identified such as the onset of movement, achievement of target, and release away from target. This set of landmarks comprises the internal, temporal structure of gestures. The notion of gesture and gestural coordination in speech are discussed further in chapter 2.

It has also been observed that gestures maintain a consistent relation with one another in the sense that a particular gesture may begin to be formed at the same time as another gesture reaches its target or release stage. This intergestural timing relation between gestures is known as phasing (Hall 2003). During speech production, gestures can be synchronized either in close transition as a result of a greater degree of coarticulation and overlap, or out of phase where there is a lesser degree of coarticulation and overlap leading to the occurrence of a vocalic element between the gestures in the process of epenthesis.

Being more phonetic than phonological in nature, the notion of ‘gesture’ in this study will consider gestures as concrete articulatory movements, viewing these as real movements of the articulators since they can be observed using acoustic analysis and EPG, rather than as abstract components in the mental representations of phonological units/phonemes. Viewing gestures from this perspective facilitates describing processes such as gestural coordination, the influence of one speech segment on another, and epenthesis, where there is a lesser degree of overlap between adjacent segments resulting in an intervening vocalic element, where both are the main goals of this study.

1.4 Focus and purpose of study

The current study investigates intergestural timing and coordination of stop consonant gestures across the word boundary in Tripolitanian Libyan Arabic (henceforth TLA). Interest in this study was initially prompted by a study conducted by Ghummed (2008) which investigated the production of English consonant clusters by Libyan learners of English. The results of that study showed that Libyan speakers faced production problems with clusters exceeding two consonants, specifically onset position three-consonant clusters and coda position three and four-consonant clusters. This was explained as due to the fact that the phonotactics of Libyan Arabic (henceforth LA) prohibit the formation of clusters of more than two consonants in both syllable-initial and final position. However, during continuous speech, word boundaries give rise to phonological sequences of consonants that do not occur within a syllable. In continuous speech, consonant sequences of more than two consonants do in fact exist but in different contexts, i.e. consonant sequences across syllable and word boundaries. An example of a sequence of three consonants across a word boundary can be found when a word ending in a coda singleton consonant is followed by another word beginning with an onset two consonant cluster CVC#CCVC, where # denotes a word boundary, as in /fak#tkasir/, *jaw broke*. Furthermore, a coda cluster may also be followed by an onset singleton CVCC#CVC as in /fatg#gal/, *the hernia improved,* which produces a three consonant sequence. Finally, four consonant sequences CVCC#CCVC also exist as in /fatg#gdi:m/[1] *old hernia.*

These examples raise a number of interesting issues. It will be argued here that the production of these forms may lead to the occurrence of different phonetic and phonological processes such as epenthesis, assimilation, and resyllabification as a result of phonotactic limitations and articulatory demands in order to repair these forms. When faced by complex articulatory demands in continuous speech, speakers often simplify the phonetic and phonological forms in several ways (Howard 2004). For example, if a form consists of a sequence of consonants that cannot be analyzed as a grouping into permitted sequences, epenthesis is triggered (Broselaw 1983).

In this study, the process of gestural coordination or temporal co-occurrence that results from the occurrence of adjacent stop consonants during continuous speech focusing on stop consonant sequences across word boundaries is investigated. Nasal stops, emphatic stops, and fricatives are excluded from the investigation and with reference to stop consonants within the study, only lingual-palatal non-emphatic stops are dealt with. The co-ordination and phasing of stop gestures with respect to each other during speech and the stability patterns of these gestures are investigated since durational variations in the organization of these gestures as a result of differences in syllable position, place of articulation, and speech rates have been mentioned in other studies. Furthermore, the study aims to investigate interactional processes occurring between stops across word boundaries and the relative timings of gestures as one sound gives way to the next in the stream of speech. The study investigates the timing of consonant gestures in different environments and whether an increase in the number of

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[1] This example includes a juncture geminate can be found that will discussed in section 1.6.4

stops on either side of a word boundary will have an effect on the timing and duration of the stop gestures involved, i.e. whether the timing and durations of the stop gestures in a sequence such as C#C, where # denotes a word boundary, differ as the number of consonants increases as in CC#C, C#CC, and CC#CC sequences.

Processes such as epenthesis and voice assimilation will also be investigated as part of this study. The aim is to identify the different patterns of epenthesis occurring between stops in different consonant sequences in addition to the duration of the vocalic elements that arise. As for assimilatory processes in this study, these will be limited to voice assimilation across word boundaries in TLA.

The research aims to provide a description of the interaction between consonants across word boundaries in TLA. In order to carry out this investigation, speakers of TLA were recorded and this data was analyzed by the use of speech analyzing computer software such as EPG and PRAAT. Native speakers of TLA with no known speech or hearing impairment were selected to participate in the research.

The results of the study will shed light on stop consonant interaction at word boundaries. It will focus mainly on how speech gestures across word boundaries are temporally organized during speech with the aim of describing their stability patterns. It will also describe durational variations in the organization of these gestures as a result of differences in speech rates

A review of the relevant literature reveals that to date few experimental studies have investigated Libyan Arabic. To the best of my knowledge, no studies have so far detailed and described stop production during speech in TLA. This acoustic and articulatory study of stop consonant sequences will also contribute to future research on TLA.

1.5 Previous studies

Very few studies have been conducted on Libyan Arabic and its dialects. One of the earliest linguistic studies was carried out by Mitchell (1952) who described the dialect spoken in Eastern Libya. More recently, most research on LA has been conducted by Libyan postgraduate researchers who have examined various dialects of Libyan Arabic. A study by Aurayieth (1982) investigates the dialect spoken in the city of Derna in Eastern Libya. In his study, Aurayieth focuses mainly on verbs but also investigates the classification of vowels according to their distinctive features. His study was conducted within the framework of generative phonology as put forward by Chomsky & Halle (1968).

Another dissertation by Abumdas (1985) investigates the dialect spoken in the city of Zliten situated in the west of Libya. Abumdas provides a detailed description of the sound system of that specific dialect.

One of the few studies conducted specifically on TLA was by Elgadi (1986). In his study, Elgadi presents a comprehensive phonological and morphological analysis of TLA within the framework of the standard theory of generative phonology. His study classifies the distinctive features of sound segments and phonological processes in TLA and details its syllable structure and morphology.

A similar study which was carried out within the framework of the standard and optimality theories was conducted by Al-Ageli (1995). His study offers an exhaustive analysis of stress and syllable structure in TLA. He also focuses on syllabification in TLA where he first analyzes syllables in the framework of the Standard Theory and then attempts an Optimality Theoretic approach to syllabification.

Another study conducted on TLA was carried out by Laradi (1983). This study was probably the first instrumental study on the Libyan dialect. In her study, Laradi investigates the phenomenon of pharyngealization in TLA. She focuses on issues related to the phonetic realization of pharyngeal consonants and the role of the epiglottis in their production. This physiological and articulatory study uses instruments and techniques such as video-endoscopic recordings and spectrographic analysis, in addition to palatographic and airflow measurements.

A more recent instrumental study focusing on Libyan Arabic was conducted by Ahmed (2008). The study provides a detailed acoustic and auditory description of the vowel inventory in Libyan Arabic and also compares the phonetic features of these vowels with those of other Arabic varieties. He divides his study into two main parts, production and perception.

In the case of LA in general, and TLA in particular, none of the studies conducted so far has investigated the acoustics and articulatory features of consonant interactional processes across syllable boundaries as with consonant sequences. This gap in the literature provides an excellent rationale for conducting this study.

1.6 Dialect under investigation

Spoken in over 20 countries in the Middle East and North Africa, Arabic belongs to the Semitic group of languages. There are many Arabic dialects used today by over 250 million speakers. A majority of the literature describes these dialects from the perspective of an East-West dichotomy. According to Kaye (1997:265), the Eastern Arabic dialects include Saudi Arabia, Yemen, Kuwait, Oman, and the United Arab Emirates, in addition to Iraq, Syria, Lebanon, Palestine, Jordan, and Egypt. The Western group includes dialects that are to the west of Egypt. These include Libyan, Tunisian, Algerian, Moroccan, and Mauritanian, in addition to several now extinct dialectal variants such as Siculo Arabic, the Arabic used in Sicily, and Andalusian Arabic, the Arabic which was formerly used in Spain.

One of the driving forces behind the initial spread of the Arabic language was Islam. During the early years of Islam, Classical Arabic was the form that was used and the Quran was also written in Classical Arabic. The large numbers of non-Arabs who converted to Islam began learning and using Arabic which facilitated the spread of this language. Classical Arabic became the language of educated Muslims and was also adopted by Christians and Jews and still exists to this day in the form of poetry and scholarly literature (Fischer 1997:188).

In the nineteenth century, the new Arab elites who emerged under the influence of Western civilization started to develop a linguistic medium that is suitable for all aspects of modern life that is now known as Modern Standard Arabic (henceforth MSA). Today MSA is the official Arabic language that is used in all Arabic-speaking countries. Al-Ani (1970:18) defines MSA as a modernized version of Classical Arabic and states that it is the language commonly used in all Arabic speaking countries today. He adds that MSA is the language of science and education, literature, press, and radio and television.

Watson (2002:8) notes that whilst the lexis and stylistics of MSA are rather different from those of Classical Arabic the morphology and syntax have remained largely unchanged. On the other hand, she claims that vernacular Arabic dialects have developed markedly over time. This has resulted in Arabic having one standard variety and a large number of regional and social dialects and means that an Arab child's mother tongue is one of these regional or social dialects while MSA is learnt at school as a part of the child's education. She also adds that MSA is confined to formal written and spoken occasions and that the regional and social dialects are used at all other times.

Although Arabic is the official and predominant language spoken in Libya, it is not the only language used by the inhabitants. Berber is also used in the Western parts of Libya by Berber minorities in addition to Tuaregs in the southern parts of the country. Due to the vast area of the country, other regional colloquial varieties of LA exist and LA can be divided into three main dialect areas, each having its own regional sub dialects. The first is Western Libyan Arabic (henceforth WLA) with the country's capital Tripoli being the largest population centre in this region. The second is Eastern Libyan Arabic (henceforth ELA) with the city of Benghazi being the largest population centre. Finally, the third dialect is Southern Libyan Arabic (henceforth SLA) with the largest city in the south, Sebha, being the population centre for that dialect (figure 1.1).

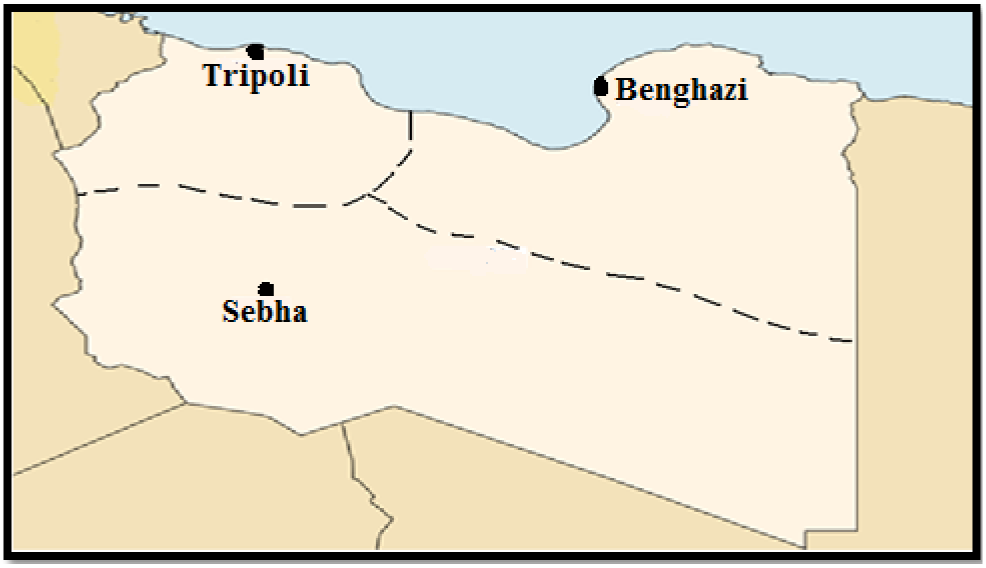

Figure 1.1 Map of Libya showing the three main dialect capitals from (http://mapsof.net/ map/libya-blank-map) Boundaries as shown are not precise

As stated earlier, each regional dialect has its own sub dialects. For example, in the case of Western Libyan Arabic, this includes the sub dialects of TLA, Zliten Libyan Arabic, Zawiya Libyan Arabic and others. The dialect under investigation in this study is TLA. In order to illustrate the differences between MSA and the different eastern and western dialects in Libya, Table 1.1 below presents a list of words and the way they are produced in MSA, TLA, and ELA. The table highlights the differences in the structure of the syllable and therefore the phonotactics of these dialects:

MSA	TLA	ELA	Gloss
/'kataba/	/'ktab/	/ki'tab/	*he wrote*
/'kabi:r/	/'kbir/	/ki'bir/	*big*
/'baqara/	/'bogra/	/'bgara/	*cow*
/'kiðb/	/'kidb/	/ki'dib/	*lie (v.)*

Table 1.1: Differences in syllable structure between MSA, TLA, and ELA

The examples reproduced in Table 1.1 make it clear that the syllabic template of TLA differs from MSA in that, according to Al-Ani (1970:78), consonant clusters never occur initially in Arabic whereas TLA allows the formation of consonant sequences in initial position. Differences are also noticeable between TLA and ELA. Where TLA allows the occurrence of consonant clusters in both syllable-initial and syllable-final positions, ELA attempts to minimize the occurrence of these clusters. This further highlights the focus of this study. Given that final position consonant clusters are permitted in TLA in both syllable-initial and syllable-final positions, therefore in continuous speech it is possible in TLA to encounter consonant sequences of two, three or four stops across word boundaries.

TLA has also been influenced by a number of other languages through contact and colonial occupation including Maltese, Spanish, Turkish, and finally Italian. This has resulted in a number of loanwords, especially Italian, being incorporated into TLA which are still used to this day, a few examples of which are provided in Table 1.2:

TLA	**MSA**	**Italian/*English***
/'garaʒ/	/'mirʔæb/	garage/ *garage*
/ kæn'ʃe:lu/	/ba'wɑ:ba/	cancello/ *gate*
/'freno/	/ma'ka:biħ/	freno/ *brake*
/kamræ'da:lja/	/du:'la:b#hawa/	camerad’aria/ *inner tube*
/ban'ju:/	/ħawdˤ#istiħmam/	bagno/ *bath tub*
/'lamba/	/mis'ba:ħ/	lampada/ *lamp*

Table 1.2 Loan words in TLA and counterparts in MSA

TLA is spoken in the Libyan capital city Tripoli and surrounding areas. With an area of 1,759,540 km^2 and a population of 6,461,454 inhabitants, Libya has a relatively small population in a large land area. Due to the fact that 80% of the land is covered by desert, most of the population is concentrated in the northern coastal cities and towns where temperatures are lower and with a higher average rainfall. According to the United Nations Statistics Division (2008) the population density is 50 persons/ km^2 in the northern coastal provinces of Tripoli and Benghazi but this falls to less than one person/ km^2 in other areas. The majority of the Libyan population is young with 30% of the population being under 14 years of age.

The Libyan economy largely depends on oil production. With the largest proven oil reserves in Africa, oil constitutes 95% of the country's exports. Revenues from these oil exports have helped Libya to develop its education sector and concentrate on providing free education for all its citizens. As a result, Libya has one of the highest literacy rates in Africa and according to The World Factbook (2008) the literacy rate is at 89.2%. The population of Tripoli, according to Libya's Urban Planning Agency (2007), is approximately 1.59 million inhabitants. The nation's capital is home to the largest and most important institute of higher education in Libya, Tripoli University. With nine different faculties and approximately 50,000 students and staff, Tripoli University was the first university founded in Libya and it played a major role in graduate and post graduate education in Libya. Although it is the only state run university in the city, it is not the only higher education institute in Tripoli. Tripoli sub-region, according to the National Consultancy Bureau (2007) hosts eight universities including the Open University which offers distant learning, the largest being Tripoli University. Currently, the total number of Higher Education students in Tripoli is approximately 77,000 with a majority enrolling at Tripoli University and about 8,000 students at the Open University.

Not all of the inhabitants of Tripoli can be considered to be natives of the city or speakers of TLA due to the large-scale internal migration from rural areas into large cities that began in Libya in the late 1960s and still continues to this day but at a lesser rate. For purposes of this study, in order to be considered a native of Tripoli and thus a speaker of TLA, a participant must have been born, raised and educated in the city itself, and must still continue to make Tripoli his or her permanent place of residence.

1.6.1 Stops in TLA

There are several differences between MSA and TLA. The basic difference between the two is the vowel system and the consonantal inventory of these two varieties. In line with other studies in TLA (Laradi 1983:9), (Elgadi 1986:5), it is argued here that the consonantal phoneme inventory of TLA consists of a total of 28 phonemes (Table 1.3). There are nine plosives /b,d,dˤ,t,tˤ,k,g,q,ʔ/. The voiceless uvular plosive /q/, is normally usually used in TLA only in words which have been borrowed directly from MSA, for example, /qura:n/ *Quran*. In other contexts this phoneme is usually replaced by the voiced velar /g/. There are also a total of thirteen fricatives in TLA, namely /f,v,s,z,sˤ,zˤ,ʃ,ʒ,ɣ,x,ħ,ʕ,h/. The voiced labio-dental fricative /v/ is only used in loanwords from other languages such as /venzwela/ *Venezuela* and is usually replaced by the voiceless counterpart /f/. TLA has only two nasal consonants /m,n/. Similarly there are two liquids /l,r/ and two glides /w,j/.

Place of articulation	**Manner of articulation**				
	Plosive	**Fricative**	**Nasal**	**Liquid**	**Glide**
Bilabial	b		m		w
Labio-dental		f,v			
Dento-alveolar	t,d,tˤ,dˤ	s,z,sˤ,	n	l,r	
Post-alveolar		ʃ,ʒ			
Palatal					j
Velar	k,g				
Uvular	q	ɣ,x			
Pharyngeal		ħ,ʕ			
Glottal	ʔ	h			

Table 1.3 Consonant inventory of TLA

It is worth noting that there are a number of phoneme variations between MSA and TLA. For example, the MSA voiced dental fricative /ð/ as in /ðahab/ *gold* is realized as a dental stop /d/ in TLA and would therefore be realized as /dhab/. Another example is the voiced emphatic dental fricative /ðˁ/ as in /ðˁuru:f/ *circumstances* which is also realized as an emphatic alveolar stop /dˁ/ in TLA and therefore /dˁuru:f/. These correspondences between MSA and TLA increase the frequency of the usage of stops in TLA.

1.6.2 Vowels in TLA

In addition to the previously described differences in the consonant system, the vowel system of LA also differs from MSA. The vowel system of MSA has a total of six vowels (Watson 2002:21). These can be divided into two groups according to their length. Close, front, unrounded vowels /i/ and /i:/. Open, central vowels /a/ and /a:/. Finally, close, back, rounded vowels /u/ and /u:/.

In addition to the vowels found in MSA, LA also has additional vowels in its inventory. In his study of LA vowels, Ahmed (2008:84) points out that in addition to the six vowels found in MSA, LA has two more vowels which are the mid front long vowel /e:/ and the mid back long vowel /o:/. The examples listed in Table 1.4 are have been taken from Ahmed (2008:84):

vowel	**word**	**gloss**
i:	/gi:s/	*measure*
i	/mis/	*touch*
u:	/mu:s/	*knife*
u	/bun/	*coffee*
e:	/be:t/	*home*
o:	/mo:t/	*death*
a:	/fa:t/	*passed*
a	/ran/	*rang*

Table 1.4 Vowel in LA adopted from Ahmed (2008)

Aurayieth (1982:23) adds that a short mid back vowel /o/ also occurrs in the vowel inventory of LA but only in the dialects of north eastern Libya, citing the examples /ʔilbiso/ *they wore* and /ʔimisko/ *they held*. However, Ahmed (2008:84) disputes this claim pointing out that /o/ is actually an allophone of the mid back long vowel /o:/ when occurring in word final position and is long in the medial position as in the examples /ʔilbiso:ha/ *they wore it* and /ʔimisko:ha/ *they held it.*

Some studies of LA also claim the existence of emphatic vowels as independent phonemes in the vowel inventory of LA. In his study of the dialect spoken in the city of Zliten, Abumdas (1985:47) claims that the emphatic vowel /ɑ/ is an independent phoneme and not an allophone of the plain open central vowel /a/. The following are some of the examples he cites in order to support his claim:

Plain	***Gloss***	**Emphatic**	***Gloss***
/ˈballah/	he wet	/ˈbɑllah/	by God
/ˈbæ:læh/	his attention	/ˈbɑ:lɑh/	spade

However, Ahmed (2008:87) argues some researchers specializing in Arabic dialects such as Lebanese (Obrecht 1968, Nasr 1959) and Palestinian (Card 1983) consider the consonants /l/ and /b/ to be emphatics, which in their opinion explains the reason why emphasis has spread to the adjacent vowel. Ahmed also adds that emphatic vowel distribution in LA is similar to MSA in that they occur close to emphatic consonants.

Auerayith (1982:24) points out that the role played by emphasis between consonants and vowels is uncertain. Some studies claim that vowels are the source of emphasis affecting neighboring consonants whereas other studies view that consonants themselves as being the source of emphasis. Youssef (2013) pursues emphasis spreading as a process of place assimilation. In his study of Cairrene and Baghdadi Arabic, he states that a V-place[dor] feature spreads bidirectionally from an emphatic segment to other segments and this spreading is subject to other factors such as the identity of the contrastive emphatic triggers and the domain of spread of the emphatic feature. However, this argument lies beyond the scope of this study. As previously stated, all stops occurring in the sequences under investigation in this study are non-emphatic lingual-palatal stops occurring in monosyllabic words with non-emphatic vowels.

1.6.3 Syllabic template of TLA

In order to investigate consonant sequences across word boundaries in TLA, an attempt will be made firstly to identify the consonant cluster combinations at syllable edges that are permissible in this variety, in other words, the syllabic template of TLA. As previously established, very few studies have investigated Libyan Arabic and even fewer have dealt with TLA. These studies differ in their claims with regards to the syllabic template of Libyan Arabic. According to El-fitoury (1976), Libyan Arabic has both two and three consonant clusters and that two consonant clusters occur in both initial and final position but three consonant clusters only occur initially. Laradi (1983) identifies the syllabic template of TLA as being $C_3^1VC_2^0$ thus allowing between one and a maximum of three consonant clusters in onset position and between zero and a maximum of two consonant clusters in coda position.

In his study of the morphology and phonology of TLA, Elgadi (1986) states that TLA has ten different types of syllables and agrees with the syllabic template of this variety is $C_3^1VC_2^0$ proposed by Laradi (1983). So far these studies all agree that the syllabic template of TLA is $C_3^1VC_2^0$. However, the examples they provide in support of their claim that TLA allows sequences of three consonants in onset position, such as /nftaħ/ *it opened*, and /ltħam/ *it welded* (Figure 1.2), are questionable:

Figure 1.2 Sonority violating onset clusters in TLA

According to the Sonority Sequencing Principle (SSP), the constraints which determine consonants occurrence in a sequence are governed to a large extent by the sonority scale (Kreidler 1997:91). In other words when two consonants occur in a sequence, they follow the scale of sonority in which those which are highest in sonority followed are by liquids, glides, nasals, fricatives, and finally stops. In an initial consonant cluster, the first consonant has to be lower in sonority than the second consonant (Ohala 1999:400). Both of the three-stop onset clusters in the above examples would thus violate the SSP. It can be argued that C1 of the onset clusters in both examples actually belong to another syllable and therefore resulting in /ʔin.ftah/ and /ʔil.tham/ as Figure 1.3 demonstrates:

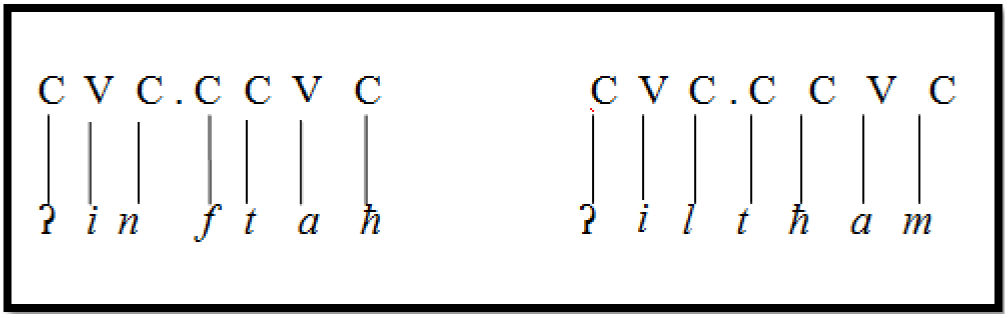

Figure 1.3 Consonant sequence conforming to SSP in TLA

In line with this assumption, a study by Al-Ageli (1995) argues that TLA has a syllabic template of $C_2^1VC_2^0$, allowing a maximum of two consonant clusters occurring in initial and final position. This is in line with the previous studies in terms of coda position consonant clusters.

Being a native speaker of TLA, my intuition is that the syllabic template of TLA will be $C_2^1VC_2^0$, thus in agreement with Al-Ageli (1995). Given this, TLA realizes the following syllable forms:

Syllable	TLA	Gloss
CVV	mʃe:.tu	did you go (pl)
CVC	fak[2]	jaw
CCV:	mʃe:	did he go
CCVC	dkar	male
CVV	fii	in
CV:C	ki:f	how
CVCC	wagt	time
CCV:C	sha:b	clouds
CCVCC	ʃrabt	I drank
CCV:	tˤri:	ripe

Table 1.5 Syllable forms in TLA

1.6.4 Consonant clusters in TLA

Given the syllabic template of TLA as $C_2^1VC_2^0$, it therefore differs from the syllabic template of MSA. In addition to allowing the occurrence of consonant clusters in syllable-final position as in MSA, TLA also allows the occurrence of two consonant clusters in syllable-initial position. This increases the frequency of occurrence of consonant sequences across word boundaries in TLA which is the main focus of this study.

Unlike singletons, a formation in which two or more consonants are found in or across a syllable is known as a consonant cluster or sequence. Due to the fact that the production of consonant clusters involves the spatiotemporal organization of different gestures and this leads to the overlapping of the gestures involved, consonant clusters constitute one of the most complex sequences of speech. Clusters can be divided with reference to their position in or across syllables. Consonant clusters that occur at the beginning of syllables before vowels are referred to as syllable-initial or onset clusters (henceforth SI), whereas consonant clusters occurring in final position after vowels are known as syllable-final or coda clusters (henceforth SF). The final types of clusters are

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[2] In this example, /k/ is a geminate

those spanning syllable or word boundaries which are the main focus of this study. If the consonant sequence spreads across the syllable or word boundary, it is then known as a sequence of abutting consonants (Abercrombie 1967:76). In this study, this third type of consonant clusters will be referred to as a consonant sequence (henceforth CS).

According to the place of articulation of the consonants involved, consonant sequences can be divided into two main types, homorganic and heterorganic. Homorganic are consonant sequences in which the segments adjacent to the word boundary share the same place of articulation. An example of a homorganic CS in TLA is /ʃid#tal/ *hold a wire.* In this example, the stops spanning the word boundary differ in their voice qualities. In cases where these stops share the same voice qualities, being either both voiced or voiceless, they are referred to as geminates.

Geminate consonants can also be considered as homorganic sequences (Catford 1988:111). They are also referred to as juncture geminates and since they each belong to separate words it is possible to split them. Juncture geminates can be distinguished from single consonants in terms of their duration. Juncture geminates are also known as fake geminates. They arise from identical consonant sequences that span a morpheme boundary within a word or in a phrase (*e.g. un+named, fun name*). Whilst true geminates are phonetically long segments that contrast with phonetically short segments in a phonemic inventory, juncture geminates are phonetically long segments that are not contrastive (Oh et al. 2012). An example of a homorganic CS constituting a juncture geminate in TLA can be found in /fatg#gal/ *the hernia improved.*

On the other hand, a heterorganic consonant sequence is where the consonants involved can be manipulated independently from each other. In other words, the consonants of this type of sequence are produced with different articulators (Catford 1988). In TLA, an example of a heterorganic CS can be found in /ʃad#gtal/ *caught and killed.*

As previously stated, the following across word boundary consonant sequences are permissible in TLA starting with the minimum across word boundary sequence of two consonants, and increasing to three consonants, and finally four consonants:

Number of stops	**Sequence**	**Example**	**Gloss**
i- 2-stop sequence	C#C	ʃid#dis	*hold and hide*
ii- 3-stop sequence	CC#C C#CC	fatg#gal fak#dkar	*the hernia decreased* *male jaw*
iii- 4-stop sequence	CC#CC	wagt#gdi:m	*old hernia*

Table 1.6 Consonant sequences permissible across word boundaries in TLA

Therefore the maximum number of across word boundary consonant sequences will result in the four-stop sequence CC#CC as seen in /fatg#gdi:m/ *old hernia*. It is argued in this thesis that the production of the consonant sequences in (ii) and (iii) will have an effect on the timing of consonants and will also result in processes such as epenthesis and possibly resyllabification. This is due to the fact that the total number of consecutive consonants in these examples exceeds the number of consonants permitted in the syllabic template of TLA.

This chapter presented a brief overview of the outline and the theoretical framework of the study. The dialect under investigation was also introduced including the phonemic inventory of TLA. Due to the fact that the study focuses on stop production in TLA, the following second literature review chapter introduces the articulatory mechanism and acoustic properties of oral stops. The chapter also presents the main factors affecting gestural coordination and resulting inter-consonantal intervals that arise from specific gestural coordination patterns.

Chapter 2 The articulatory and acoustic phonetics of oral stops

2.1 Introduction

This second literature review chapter is divided into four sections and focuses mainly on describing stops from an articulatory and acoustic perspective in addition to speech production processes. The aim of this chapter is to present the different types of speech processes investigated in this study in addition to presenting the theoretical framework that is being adopted. The first section deals with the mechanism, and phases of stop production and vocal fold vibration in relation to these phases. The second section focuses on speech processes such as coarticulation and assimilation that occur as adjacent segments influence each other during speech with more focus on voice assimilation in stop sequences. The third section introduces the theoretical framework of Articulatory Phonology that is adopted in this study. This section introduces the notion of gestures and articulatory timing in addition to how these gestures are temporally and spatially phased and coordinated with each other during speech which is the main focus of this study. The third section also discusses the factors that influence the timing relations between gestures which include the effect of place of articulation of gestures involved, the effect of speech rate, and the effect of sequence position. The fourth section is dedicated to the different types of inter-consonantal intervals occurring between stops in different sequence types. This section provides an overview including the cause and function of epenthesis and the different patterns of epenthesis that occur. The nature and quality of epenthetic vowels are also discussed.

2.2 The mechanism of stops

Stops are characterized by acoustic properties that vary rapidly over the period of their production. A unique feature of stop consonants is the momentary total closure of the vocal tract in addition to a velic closure which prevents air from escaping through the nasal cavity and the buildup of intra-oral pressure (Laver 1994). Due to the presence of this obstruction, little or no acoustic energy is produced. At the release of this closure, pressure is released in the form of a burst or transient. The release burst continues until the pressure behind and in front of the location of the closure becomes equal. These different degrees of constriction manipulate airflow in different manners to produce different sounds. During the process of pulmonically driven speech, the only instance where the oral tract is totally closed is during the hold phase of stops.

The production of stops always involves two articulators, one being the active articulator and the other being the passive articulator. Since the lower jaw is the part of the head that is mobile, all active articulators, except for the upper lip and the velum, are attached to the lower jaw. Abercrombie (1967:141) distinguishes three phases in his discussion of the function of stops in connected speech. The first is known as the shutting phase, the second as the closure phase, and the third and final phase is the opening phase (Figure 2.1). Abercrombie adds that a plosive involves the momentary but complete obstruction of the airstream that begins as soon as the first phase is completed. This continues until this obstruction of the airstream is removed as the third phase commences. Ashby & Maidment (2005:56) refer to these three phases as ‘approach’, ‘hold’, and ‘release’ respectively and in this thesis, therefore, the closure phase will be referred to as the hold phase (henceforth HP).

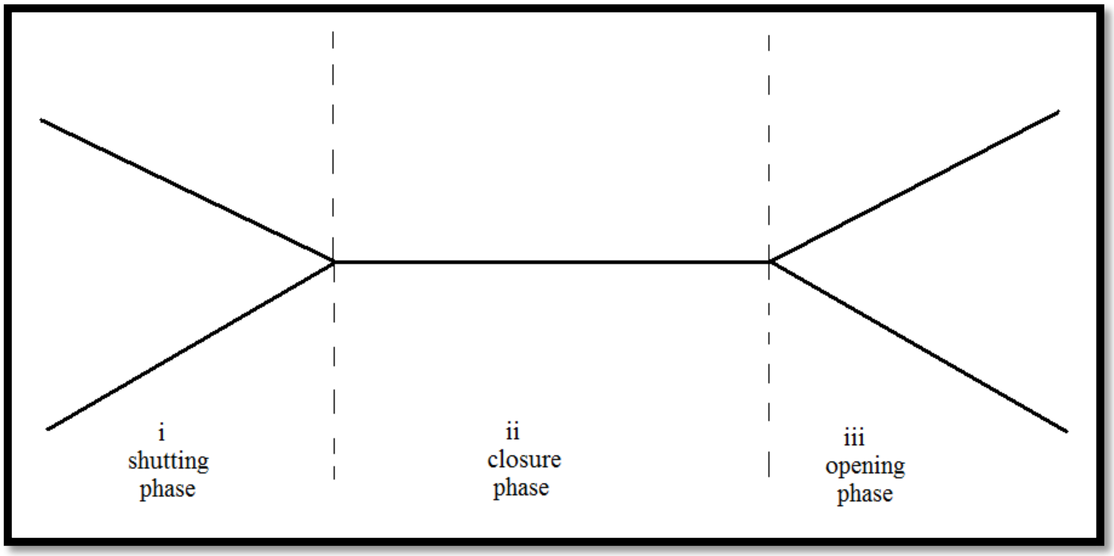


Figure 2.1 Phases of stop production adopted from Abercrombie (1967:140)

During the second phase, air pressure behind the closure increases if the airstream is egressive. Phase three is accompanied by an equalization of this pressure resulting in a plosion where the compressed air explodes outwards. In the production of all plosive stops, the pressure build up behind the closure continues until the active articulator is pulled away from the passive articulator in a sudden movement (Abercrombie 1967:141).

Stops can be distinguished by their place of articulation, in other words where in the vocal tract the obstruction is taking place. In TLA, this can be bilabial, dento-alveolar, velar, uvular, or glottal (see table 1.2). For example, a velar closure for the production of /k/ and /g/ is formed by raising the back of the tongue, which is here considered as the active articulator, up against the velum which is considered to be the passive articulator. In the case of a dento-alveolar closure as in the production of /t/ and /d/, the tongue tip/blade, which is considered as the active articulator, is raised up against the back of the upper front teeth and the alveolar ridge forming the closure. In the case of a labial closure as in the production of /p,b/, the lower and upper lips are brought together forming the closure. In some cases, both these articulators are considered to be active since the upper lip can also be lowered. However, it is worth mentioning that the sequence of stops under investigation in this thesis will consist of the non-emphatic lingual-palatal stop phonemes /t/, /d/, /k/, /g/ occurring across word boundaries.

During the production of plosive stops there are two occlusions occurring simultaneously. The first occlusion is the velopharyngeal occlusion which prevents air flowing through the nasal cavity. The second is formed by either the lips or tongue depending on the place of articulation of the stop being produced. It is usually the case that the occlusion in the oral tract is lowered first for oral plosives but in some cases the velopharyngeal port is lowered first resulting in a nasal release which occurs when a stop is followed by a homorganic nasal such as in the word English word /hidn/ *hidden* (Borden et al. 2003:111).

In the production of most oral stops, the release of the occlusion is central, in other words the airstream resulting from the pressure build up behind the closure is released through the centre of the mouth. But in some cases this release is not central and the centre of the closure is maintained as it would be in a lateral release. Abercrombie (1967:145) states that lateral plosions occur when the contact of the articulators used in the production of the occlusion is maintained in the centre of the vocal tract and the sides are released. He adds that lateral plosion can be found when a plosive is followed by a homorganic lateral. For example, in TLA, lateral release of the plosives /t/ and / tˤ/ can be found within words and across word boundaries as in /tlata/ *three* and /bɑtˤl/ *hero.*

During the hold phase, there is very little acoustic information and this is sometimes accompanied by low-level amplitude in the case of voiced stops conveying very little information on the place of articulation of the stop (Barry 1984). However, this phase, also known as the silence phase, has a duration ranging from 50ms to 100ms and can be used as a perceptual cue for identifying stops (Kent & Read 1999:140).

With regards to LA, there does not seem to be any thorough study of stop durations which further highlights the importance of this thesis. However, studies of the timing of stops in other Arabic dialects exist. In their study comparing the phonetic implementation stop voicing contrast in Saudi Arabic and American English, Flege & Port (1981) measured the hold phase of stops in both languages. With regards to Saudi Arabic, the hold phase of SI /b/, /t/, /d/, /k/, and /ɡ/ were relatively shorter than their SF counterparts. They also concluded that the place of articulation of both SI and SF stops had a significant effect on the duration of the hold phase.

Another study investigating the spectral and temporal characteristics of sounds in Egyptian Arabic was conducted by Shaheen (1979). In this study Shaheen claims that the hold phase for voiceless stops in Egyptian Arabic were relatively longer in duration than their voiced counterparts and that the place of articulation of the stop also affected the duration of the hold phase (Shaheen 1979:102).

However, the above studies only focused on the duration of the HP with regards to singleton stops. In the study by Flege & Port (1981), the data consisted of monosyllabic words with SI and SF singletons. Likewise, Shaheen (1979) only investigated the HP for SI singletons in monosyllabic words. Neither study investigated what effect adjacent stops in a stop sequence might have on the HP. Furthermore, there do not seem to be many studies investigating the timing of stops across word boundaries which is the topic to be explored in the current study. Most studies have focused on CV coarticulation and not CC. There are several factors that have an effect on the timing of stop gestures that both studies failed to investigate. These are the number of stops in a sequence, the effect of position being within a word or across a word boundary, and the effect of the order of place of articulation of the stops involved. These factors also play a role in determining the degree of gestural coordination between stops in sequences as are further discussed in section 2.4.2. This gap in research provides a good opportunity to investigate the duration of stops in TLA in different stop sequence types across the word boundary.

2.2.1 Release phase and aspiration

The articulatory production of stop consonants is not the only way to define them; they can also be described by their acoustic characteristics which are found in the release or ‘offset’ phase. The release phase of stops conveys most of the acoustic information which includes the release burst or transient. The release burst provides the most direct acoustic manifestation of the place of articulation of a stop (Repp & Lin 1988:17). It is vital for the perception and identification of the stop. The absence of a release of a stop when masked by the closure of a following stop in a stop cluster especially in SI position can threaten its perceptual recoverability (Chitoran et al. 2002:9). They also add that as a result of the limitation of acoustic information for C1 in a SI cluster, the degree of gestural coordination between C1 and C2 is restricted in order to preserve as much acoustic information as possible for each stop and therefore it becomes crucial for C1 to be acoustically released in SI position since the acoustic release is the only information available on the presence and nature of that stop. This was also found in an EPG study by Byrd (1996) in which consonant gestures in SI clusters exhibited less temporal overlap than SF clusters and therefore more C1 releases in SI position. This is also the case in TLA as in the following examples:

/tkasir/ — broke
/ktab/ — book
/dkar/ — male

In the above examples, C1 of the underlined SI cluster is always released. During the release stage, an increase in acoustic energy occurs as a result of the sudden increase in air flowing through the released constriction and also a rapid decrease in intraoral pressure. The duration of this stage can vary and usually does not exceed 20-30ms (Kent & Read 1999:145).

Borden et al. (2003:111) state that when stops are released orally, an audible burst of noise can be heard as a result of the outward rushing air that was trapped by the occlusion. They claim that this burst is part of the release phase and is an example of an aperiodic sound source. To a certain extent, this is similar to friction that is produced during the production of fricatives but it differs in that it is transient or temporary, only lasting about 20ms. In the production of oral stops in sequence as in C1C2, it is sometimes the case that the release of C1 is masked by the hold phase of C2. Due to a high degree of coarticulation resulting in closer gestural coordination, the gestures of stops sometimes overlap and there is no acoustic evidence of the release of C1.

The release phase of aspirated stops can be divided into three main events: 1) transient, 2) frication, and 3) aspiration. These phases overlap in natural speech and are sometimes difficult to identify in the waveform (Repp & Lin 1988:19), and for this reason, the HP of stops is considered to be the most stable phase of the stop production. The transient is a result of the sudden pressure release. It is usually characterized by a vertical spike on the waveform and a burst of energy on the spectrogram after the silent hold phase marking the point of release. In the case of voiceless aspirated stops such as /tʰ/ and /kʰ/, this vertical spike is very clear on the waveform and corresponds to high spectral energy reaching 4000Hz on the spectrogram. On the other hand, in the case of voiced stops such as /b/, there is sometimes no evidence of high energy on the spectrogram due to the low intensity of the burst. This spectral variation is due to the fact that the transient burst is controlled by specific articulatory configurations where labials have low-frequency energy bursts, alveolars have high-frequency energy bursts, and velars have mid-frequency energy bursts (Kent & Read 1999:145).

The transient burst is sometimes followed by a frication interval. Frication results from turbulence generated at the constriction at the point where they have just separated. It has the same acoustic properties of fricatives due to the fact that the articulators are still relatively close to each other. As for aspiration, this segment is a result of glottal friction that replaces the frication at the constriction as the articulators move further apart. Aspiration is defined as the period where there is no vocal fold activity between the release of a stop and the onset of voicing of the following vowel (Ladefoged, 2001). In TLA, voiceless non-pharyngealized stops can be aspirated (Laradi 1983:11).

Voiced stops are unaspirated and formant transitions into the following vowel can be identified immediately following the transient whereas for voiceless stops, formant transitions are sometimes delayed as a result of aspiration. Formant movements at the release phase of stops also provide information relevant to the place of articulation of the stop (Ladefoged, 2006). Stops convey their quality by their effect on the formants of adjacent vowels. Formant patterns at the moment of release into a following vowel are determined by the quality of the following vowel. Transitions of the second and third formants that reflect vocal tract changes as the tongue moves into position for the following vowel are sufficient cues to the place of articulation of stops (Dorman et al. 1977:110). According to Lieberman & Blumstein (1988:225), in terms of perception, stop bursts and formant transitions do not act as separate cues for the perception of the place of articulation of stops and to a certain degree are treated as an integrated cue. They add that continuity exists between the burst frequency spectrum and the frequency spectrum of the formant transitions.

2.2.2 Vocal fold vibration and VOT

The final feature of stops is voicing, which is the presence or absence of vocal fold vibration during the production of the stop. In fully voiced stops, vibration begins during the approach phase and continues throughout both the HP and release phase. In order for the vocal folds to start vibrating air has to flow through the glottis resulting in a rapid air pressure build up behind the occlusion. This buildup of supraglottal air pressure causes the termination of transglottal airflow when the pressure reaches a certain level and results in the termination of voicing (Torres 2001). Therefore, the closure cannot be maintained because of this build-up of pressure. However, this can be overcome by expanding the cavity behind the occlusion, for example, by expanding the pharyngeal cavity by lowering the larynx, advancing the tongue root, or puffing out the cheeks. Voiceless plosives on the other hand are relatively longer in duration. The reason for this is that during the hold phase, there is no vibration in the vocal folds and therefore the duration of the HP can be increased. What distinguishes the different types of voiceless plosives is the beginning of vibration of the vocal folds in relation to the release of the burst. In some voiceless plosives, vibration starts shortly after the release of the closure. Sometimes the vibration begins at a far later stage of the release of the plosive and there is a delay in the onset of vocal fold vibration. For these types of voiceless plosives, this delay is a result of aspiration. In some cases the release of a stop consonant coincides with the onset of periodic voicing of the following vowel.

An increase in the delay of vocal fold vibration results in a longer period of aspiration after the release of the occlusion of a stop. This process, known as Voice Onset Time (VOT), is illustrated in figure 2.2. VOT is defined as the time interval between the articulatory release of a stop and the onset of vocal fold vibration which signals the beginning of a vowel that follows a stop consonant (Kent & Read, 1999). It can also be expressed in terms of the timing relation between vocal fold vibration and movements of the articulators during the production of stops as highlighted in figure 2.3. Some languages, such as Korean, Chinese, and Hindi, use aspiration to show phonemic distinction between aspirated and unaspirated voiceless stops (Sawashima &

Hirose, 1983:15). In these languages, the glottal opening increases and the peak glottal width is achieved close to the point of the stop release in aspirated stops. As for unaspirated stops, although the glottis is open, the glottal width is relatively smaller. This state of the glottis during the production of voiceless unaspirated stops is referred to as 'prephonation' (Esling & Harris 2005:356).

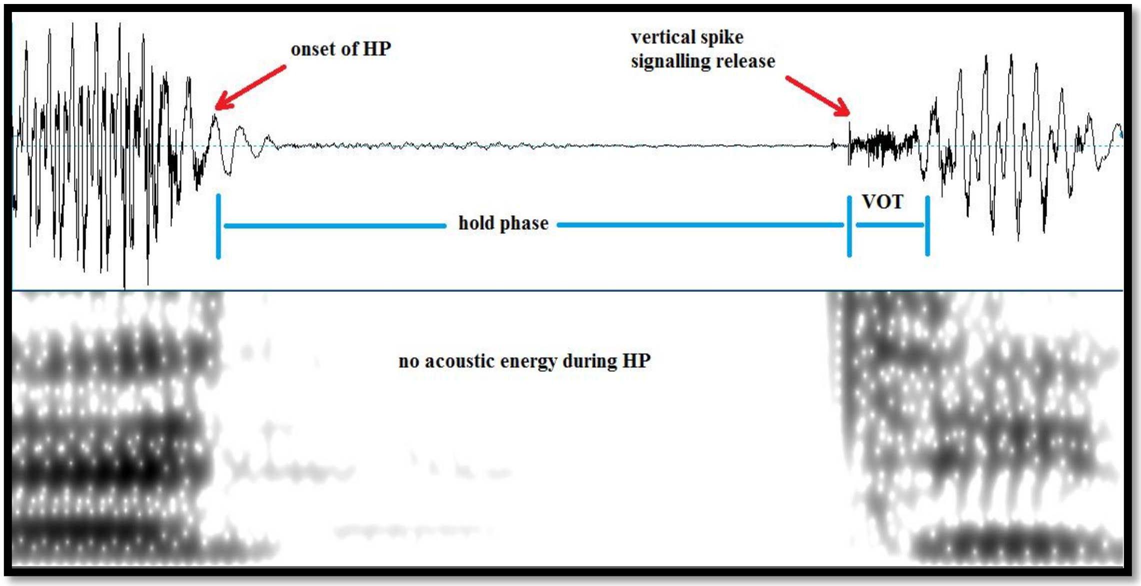


Figure 2.2 Waveform and a wideband spectrogram of the TLA voiceless stop /t/ produced in /nat/ showing HP and VOT

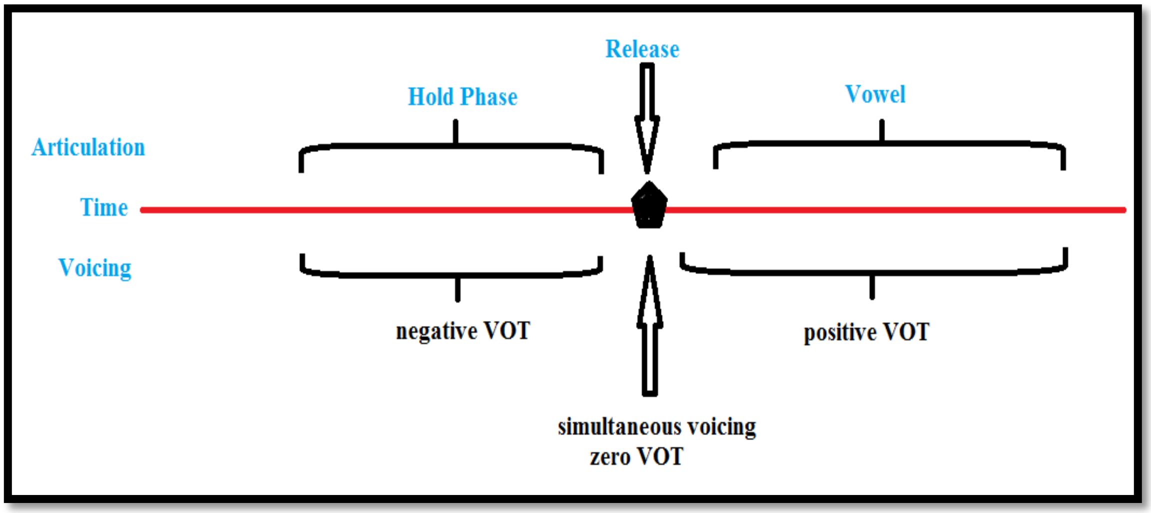


Figure 2.3 Voicing contrast in stops. Adapted with modifications from Yang (1993)

Some languages exhibit stop consonant voice contrasts. In these languages, stops sharing the same place of articulation disagree in terms of their voicing. In their study of syllable-initial VOT in different languages, Lisker & Abramson (1964) found two types of languages with two-way laryngeal contrasts. In one type of languages they had stops with negative VOT and the other with short-lag VOT such as Dutch and Hungarian which they refer to as ‘true voice languages’. In the other type of languages with two-way laryngeal contrast stops had long-lag VOT or aspirated stops and short-lag VOT unaspirated stops as in English and Cantonese.

Arabic has five voiceless stops (/t/, /tˤ/, /k/, /q/, and /ʔ/) as opposed to the three voiceless stops in English (/p,t,k/). Since VOT is language-specific, the VOT for /t,k/ in Arabic differs from that of English. According to Al-Nuzaili (1993:30), different studies of VOT durations have yielded different results. Al Ghamdi (2006:93) states that Arabic /k/ has a VOT of about 30ms and /t/ about 25ms. Al Ghamdi also reports that regional dialects in the Arabic Gulf differ in their VOT durations with results from experiments revealing that Iraqi Arabic has the longest VOT whereas Qatari Arabic has the shortest.

2.2.2.1 Factors affecting VOT

There are several factors that can affect vocal fold vibration and consequently VOT such as place of articulation, contact surface area of stops involved, and speech rate. In their study of VOT in Saudi Arabic, Flege & Port (1981:130) found that the place of articulation of the stop had an effect on VOT in Saudi Arabic. This is due to the speed of the articulators involved. Maddieson (1999:620) points out that the release movement of a velar /k/ is slower than that of an alveolar /t/ or bilabial /p/. The rotational movement of the jaws speeds the release movement of /t/ and /p/ in comparison with the back of the tongue for /k/ because the jaw pivot is closer to /k/. Any movement of the lower jaw will result in the lower lip moving further than the tongue during the same period of time. The oral opening through which air escapes during the release phase increases in size at a slower rate for /k/. As a result, more time is needed to reach the required transglottal pressure for voicing to be initiated.

Therefore the closer the articulators are to the jaw pivot, the longer the delay in vocal fold vibration and therefore longer VOT.

Another factor that contributes to VOT variations in different stops is the extent of contact between the articulators involved. Cho & Ladefoged (1999:326) state that the area of contact of a velar /k/ covers a larger surface area than that of bilabial and alveolar stops and that stops with a large surface area of contact have a longer VOT. This is further explained by Stevens (1999). The rate of change in intra oral pressure after the release depends on the rate of increase in the cross-sectional area at the constriction. A velar stop closure has a large surface area of contact and as a result a Bernoulli force acting on the articulators is larger. This results in a slow change in the cross-sectional area of the articulators in comparison with alveolar stops where a small Bernoulli effect acts on the articulators. Therefore there is a rapid decrease in intra oral pressure following the release of an alveolar stop but a gradual decrease for the velar stop. As a result, VOT is longer for velar stops than for alveolar stops (Stevens 1999:326).

In their study of the VOT of speakers from 18 languages, Cho & Ladefoged (1999) also state that VOT may vary with place of articulation and that there is a longer VOT when the closure is further back and there is a more extended contact area. They argue that due to the small cavity behind a velar closure there is a smaller volume of air than behind this closure than in the case of an alveolar closure. This also results in higher pressure behind the velar closure at the point of release of the closure. As a result, it will take a longer time for the pressure behind the closure to drop in order to reach the appropriate transglottal pressure required for initiating vibration vocal fold and therefore longer VOT.

Furthermore, an increase in the speed of the articulators involved results in the decrease of VOT (Cho & Ladefoged 1999). A faster articulatory velocity (e.g., the movement of the lower lip as compared to the tongue dorsum) allows a more rapid decrease in the pressure behind the closure and thus a shorter time is needed before building up an appropriate transglottal pressure. In their study of the effect of speaking rate on VOT, Kessinger & Blumstein (1998:125) found that changes in speech rate had an effect on VOT durations observing that as speaking rate slows in voiceless stops, there was an increase in both VOT and vowel durations.

The above applies to stop consonants occurring as singletons in SI or SF position. However, due to coarticulation, in which individual segments influence each other in connected speech, it is common that the voicing of a stop is also affected by the voicing of an adjacent stop in a sequence as a result of voice assimilation. In SI and SF stop clusters, in addition to across word boundary stop sequences, a voiced C1 may be devoiced as a result of a neighbouring voiceless C2 or a voiced C2 may become devoiced as a result of a voiceless C1. Some languages exhibit consonant clusters that only agree in voicing. These types of clusters are known as harmonic clusters because the laryngeal quality is consistent throughout the cluster (Chitoran 1998:121). One of the languages exhibiting this phenomenon is Georgian, in which the two consonants of a SI or SF cluster are both voiced, both aspirated, or both ejective. This is not the case in TLA where stop clusters in SI, SF, or across word boundaries can either agree or disagree in terms of voicing as in /dkar/ '*male'*, /*wagt*/ '*time'*, and /ʃad#tal/ '*held a wire'*. It is anticipated that this will result in voice assimilation across the word boundary which will be further discussed in section 2.3.2.1. As will become apparent, across a word boundary two-stop sequences C#C can consist of stops disagreeing in their voicing as in /ʃid#kif/ '*catch a slap'*.

2.3 Coarticulation and assimilation

One of the major difficulties encountered when studying speech production is the problem of observing how speakers coordinate various articulatory movements during the speech process. Different theories have been put forward in an attempt to describe this process in various ways. Linguists and speech scientists recognize that when phonological units are used in the production of words and sentences, their spatiotemporal realization by the articulatory organs and consequent acoustic character that is perceived by the auditory system is extremely variable and context dependant. It is a well-known fact that ‘sound segments are highly sensitive to context and show considerable influence from neighboring segments. Such contextual effects are described as being the result of overlapping articulation or coarticulation’ (Hardcastle & Hewlett 2006). In continuous speech, syllable and word boundaries are not discrete in the speech signal as segments are articulated in close coordination.

2.3.1 Coarticulation

In the production of sequences of sounds during speech, the shape of the vocal tract needs to alter in order to satisfy the requirements of all the sounds that need to be produced. Due to the fact that the vocal tract is governed by the laws of physics and physiological constraints, it cannot instantly alter its shape from one configuration to another. Thus, instead of assigning a specific articulation for a particular phoneme and have to later undergo a time-consuming transition to another, the vocal tract modifies the places of articulation of phonemes in order to rapidly fulfill sequences of sounds using varying places of articulation, thus resulting in the process of coarticulation. Coarticulatory processes are obligatory and take place automatically during speech (Recasens 1993:54).

The term “coarticulation” in linguistic studies commonly implies overlapping articulation, or an ‘articulation which takes place involving in a simultaneous or overlapping way more than one point in the vocal tract’ (Crystal 2008:82). As defined by Daniloff & Hammarberg (1973), coarticulation is ‘the influence of one speech segment upon another: that is, the influence of a phonetic context upon a given segment’ (1973:239). It is a universal process in that neighbouring segments phonetically interact with each other in all languages. According to Perkell & Matthies (1992:2911) coarticulation can be defined as “the superposition of multiple influences on the movement of an articulator” and they further note that “These influences can come from the acoustic-phonetic requirements of context and from physical interactions with other articulators”. Coarticulation occurs in all languages and involves the articulatory adaptation of a sound to its phonetic environment. According to Tatham &

Morton (2006:23) phonetic coarticulation is used to refer to influences of neighbouring segments on each other and describes effects which are not voluntarily controlled. In English for example, a phoneme such as the velar stop /k/ in '*keen'* /kiːn/ and /kɒt/ as in '*cot'* would be articulated in different positions on the palate as a result of coarticulation with the adjacent vowel. In /kiːn/, as a result of being followed by a front vowel, it will be articulated at a further front position on the palate, whereas in /kɒt/ it will be articulated further back on the palate due to the influence of the following back vowel. As a result, the tongue needs to adjust its position due to these conflicting articulatory demands. From an articulatory point of view, coarticulation is a process in which various articulators interact in space and time during the production of successive speech segments, in other words, it involves the temporal coproduction of gestures. Therefore the articulated sounds accommodate each other and the transitions between adjacent sounds are smoothed out and minimized whenever possible.

Speech consists of a series of vocal organ gestures which are realizations of canonical targets. When combined together, these targets are not fully realized as phonological assimilation and phonetic coarticulation come into play. In continuous speech, speakers temporally overlap the phonetic gestures of speech as a result of coarticulation or coproduction (Fowler 2006). In the case where two stops occur in a sequence, coarticulatory effects determine the extent to which the gestures of these stops are coordinated. On the one hand, the gestures of both stops can be completely overlapped as a result of a higher degree of coarticulation. On the other hand, due to physiological constraints, these gestures may be pulled apart as a result of a lesser degree of coarticulation. The coordination patterns and phasing of gestures will be discussed in section 2.4.

It has been emphasized that coarticulatory effects are not limited to transitions between sounds, but may also spread across syllable and word boundaries (Tunley 1999:14, Laver 1994:151). Research studies have shown that coarticulation occurs across juncture boundaries as long as the juncture is not marked by a relatively long pause since pauses at juncture boundaries tend to reduce or stop coarticulatory effects (Su et al 1975).

2.3.1.1 Previous studies of coarticulation

The experimental investigation of coarticulation has been an important area of research. Various aspects of coarticulatory phenomena have been examined in different studies on coarticulation. These phenomena include velum movement (Bell-Berti & Krakow, 1991), tongue body movement (Zharkova & Hewlett 2009; Gibbon et. al., 1993), jaw movement (Gay, 1981), lip protrusion (Daniloff & Moll, 1968; Perkell & Mathies, 1992), effects of stress and boundaries (Doty & Redford 2007: Fowler, 1981), and speech rate (Engstrand, 1988; Doty & Redford, 2007).

Studies on coarticulation have also dealt with various languages such as English (Ohman, 1966; Daniloff & Moll, 1968; Bell-Berti & Harris, 1982; Repp, 1986; Boyce, 1990; Hoole et. al., 1993), French (Benguerel & Cowan 1974), Arabic (Hussein, 1990), Italian (Farnetani & Recasens, 1993), Catalan (Recasens & Pallares, 2001; Gibbon et al., 1993), and Russian (Choi & Keating, 1991; Davidson 2007). Most of these experimental studies on coarticulation have tended to focus on the transition from vowel to vowel and from consonant to vowel and vice versa, V—›V, C—›V, V—›C. One area of coarticulation that has not been so thoroughly investigated is that of consonant-to-consonant coarticulation, C—›C.

Hardcastle (1985) investigated the lingual coarticulation of /kl/ clusters in intervocalic position in English using EPG to identify the degree of overlap in the articulatory gestures for /k/ and /l/ in different speech rates and different positions. His investigation focused on five different contexts, (1) word-initial *clock* (2) syllable boundary *backlog***,** (3) word boundary *black lock,* (4) phrase boundary *black, lock,* and (5) sentence boundary *black. Lock.* In this study, the degree of coarticulation was measured as the interval between the release of the /k/ closure to the onset of tongue movement for /l/. Hardcastle found that overlap was minimal at slow speech rate and at the phrase and sentence boundary, whereas overlap generally increased in fast speech rate, and at syllable and word boundary more than in word-initial position. Results from this study also showed that as a result of coarticulation the articulatory gesture for /l/ began simultaneously or at times before the release of /k/ for most speakers.

Using ultrasound imaging, Davidson (2007) investigated stop-stop gestural timing and coarticulation in Russian in #CəC, #CC, and C#C sequences. She recorded four speakers producing tokens of /tk/, /kt/, and /gd/ sequences and investigated the tongue shape trajectories in three sequence types. Results from her study show that the spatiotemporal differences between #CC and C#C are significantly larger than those between #CC and #CəC. Davidson states that one difference between #CC and C#C is that C1 in both sequences belong to different syllable/word positions where in the onset position it is articulated with a greater degree of constriction and longer duration. It was also found that tongue dorsum height for the constriction of /g/ in #gC and #gəC was similar in height whereas it was lower in g#C.

Davidson also claims that syllable position effects may interact with the amount of coarticulatory resistance that is integral to specific articulations. The reason why /tk/ in the #CC cluster was more similar to C#C than to #CəC may be due to the fact that tongue position for /t/ depends highly on the position of the following articulation and is therefore less resistant to coarticulation. Davidson adds that /t/ has a slightly lowered tongue dorsum position when followed by a /ə/ whereas when followed by a velar, the tongue dorsum is already raised during /t/ signalling more coarticulation.

2.3.1.2 Anticipatory vs. carryover coarticulation

Coarticulatory effects of neighbouring segments on each other can operate in both directions. The influence of one segment on its following segment is known as carryover or left-to-right coarticulation, and when a segment influences a preceding segment it is referred to as anticipatory or right-to-left coarticulation. Anticipatory coarticulation, also referred to as forward coarticulation, occurs when an articulatory adjustment for one sound is anticipated in the production of an earlier sound (Kent & Minifie 1977). An example of this type of coarticulation can be found in the anticipatory velar lowering for the nasal /n/ in the phrase *free Ontario* (Moll & Daniloff 1971). In their study, sentences containing various combinations of the nasal consonant /N/, consonants /C/, and vowels /V/ in English were investigated. Results indicated anticipatory coarticulation of velar movement toward velopharyngeal opening in CVN and CVVN sequences such that velar movement towards opening began during the approach to the initial vowel. In the above example, velar opening for /n/ actually began during the production of /i:/ in the preceding word *free*.

On the other hand, carryover coarticulation, also referred to as backward coarticulation, refers to the process where the vocal tract configuration for one speech segment influences the vocal tract configuration for a following sound (Guenther 1995). An example of this type of coarticulation can be found in the word *boots*. According to Kent & Minifie (1977), the lip protrusion associated with the production of the vowel /u/ can be found in the final /s/. In this example, carryover coarticulation results in the spreading of lip protrusion through all segments following the vowel /u/.

In this study, the temporal co-occurrence of stops in sequence will be investigated from a gestural point of view within the framework of Articulatory Phonology (see section 2.3.3) and term coarticulation in this study will refer to the degree of gestural coordination and the timing of stop gestures in different sequences in TLA. It is anticipated that a high degree of coarticulation may result in the partial overlapping of stop closures during the production of two neighbouring segments across word boundaries. The coarticulatory effects between gestures of neighboring oral stops spread across word boundaries in addition to the factors affecting gestural coordination will also be discussed (see section 2.4).

2.3.2 Assimilation

Coarticulation has been described as phonetic in nature and involving the articulatory adaptation of a sound to its phonetic environment without changing its phonological features; assimilation has a phonological nature and entails the modification of the phonological features of a sound as a result of the influence from an adjacent or neighbouring sound. Assimilation is a language specific process that varies from one language to another. The term ‘assimilation’ in linguistic studies ‘refers to the influence exercised by one sound segment upon the articulation of another sound so that both sounds become more alike or identical’ (Crystal 2008:39).

Similar to coarticulation, the direction of assimilation can also be in either way, carryover and anticipatory, and is also referred to as progressive right-to-left and regressive left-to-right. Assimilation can also be classified as partial or total. In this thesis, the terms regressive and progressive will be used to refer to the direction of assimilatory processes. However, unlike coarticulation which is obligatory, assimilatory processes are not and may be affected by factors such as speech rate (Recasens 1993:54).

Modern usage reserves the use of assimilation in reference to influences of one phonological segment on another, in addition to being voluntary or optional although it may reflect the phonetic tendencies of coarticulation. Assimilation is a phonological process that is language specific varying from one language to another. In English for example, regressive place assimilation occurs when a bilabial stop is preceded by an alveolar nasal as in the phrase *ten pounds* where the word final nasal assimilates the bilabial feature of the following stop resulting in [tem#paʊndz]. The loss of voicing or devoicing of a segment where a voiced segment becomes devoiced as a result of an adjacent voiceless segment is a phonological process of voice assimilation which will be discussed later (see section 2.3.2.1).

Jurgec (2011:9) argues that assimilation is segmental alternation which involves at least two segments. He uses the term ‘the target’ for the segment which alternates in the presence of the other segment which he terms ‘the trigger’. He adds that during the process of assimilation, the target acquires the phonological property of the trigger and that this phonological property can be characterized in terms of phonological features. In English, an example of phonological assimilation across a word boundary can be found in the phrase *that place* [ðæt#pleis] which in connected speech would sometimes be produced as [ðæp#pleis] where /t/ is the target and /p/ is the trigger.

Assimilation and coarticulation are sometimes considered as two indistinguishable or very similar processes. In drawing a distinction between coarticulation and assimilation, Laver (1994:379) describes coarticulation as the co-ordinating phenomenon of the spreading of articulatory features across neighbouring segments noting that this influence can be limited to two neighbouring segments or may extend across all the segments in a short utterance. Laver also adds that the co-ordinatory adjustment between adjacent segments in coarticulation occurs within and across a word boundary. On the other hand, he argues that assimilation is an optional process where a segment exerts a modifying influence on the articulatory or phonatory features of a neighbouring segment.

Others have claimed that assimilation is connected to linguistic competence and is accounted for by phonological rules referring to feature modification. Here the process of assimilation is part of the grammar and is language specific although it is widespread among languages. On the other hand, coarticulation is viewed as being governed by universal rules and occurs as a result of the physical properties of the mechanism of speech and is therefore connected to the performance domain and is not part of the grammar (Hardcastle et al. 2006:337). The same authors add that two factors allow for a distinction to be made between these two processes. Firstly, with regard to the distribution of contextual change, this is universal in the case of coarticulation and language specific for assimilation. Secondly, in reference to the quality of the contextual change, in the case of coarticulation this entails articulatory adaptation whilst assimilation involves feature modification.

In her study of the perceptual effects of coproduction in consonant clusters, Byrd (1992:22) proposes that assimilation should be viewed as a process which can be modelled in terms of degree of gestural overlap. She argues that coarticulation can vary in degree depending on the organization of the gestures involved and that the acoustic result of the coproduced units reflects their combined influence on the vocal tract. She adds that in casual or fast speech, the overlapping of gestures may increase to a certain degree resulting in the perception of assimilation or deletion. She uses the term assimilation in reference to an increase in perceptual similarity between two adjacent segments and posits that if assimilation is total, one segment will be perceived as having all the features of an adjacent segment. In other words, the segment will appear to have been deleted and/or replaced by the influencing segment whereas, in reality, as a result of gestural overlap, they are articulatorily present but perceptually hidden due to being acoustically unrealized. Byrd (1992:3) also adds that within the framework of Articulatory Phonology, assimilatory processes are seen as instances of gestural overlap in which a gesture is not delinked or deleted but is actually obscured by an overlapping gesture.

Assimilation can be classified in terms of the phonological features of the sounds involved. In this type of classification, assimilation can be of three types; place, voice, and manner. For this study, the process of stop voice assimilation across the word boundary in TLA will be investigated.

2.3.2.1 Voice assimilation

During the process of voice assimilation, the voicing value of a segment may be affected by the voicing of an adjacent segment. When two adjacent segments which disagree in voicing occur in a sequence, a regressive or progressive voice assimilation may be triggered. In the case of progressive or left-to-right voice assimilation, the first segment is affected by and takes the voice quality of the second segment (or trigger). Conversely, in the case of regressive or right-to-left voice assimilation, the second segment is the trigger and the first segment takes the voicing of the second segment as in **Error! Reference source not found.** below:

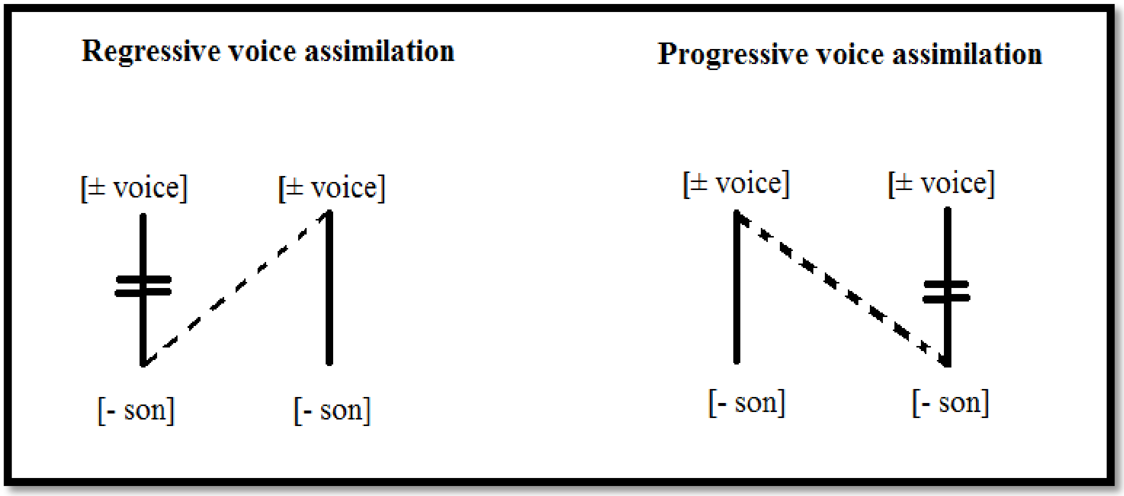


Figure 2.4 Regressive vs. progressive voice assimilation

The process of voice assimilation was thought to occur categorically where a specific voice feature for one segment is substituted by the voice feature of an adjacent segment (Teifour 1997:78). However, phonetic studies in Russian (Burton & Robblee 1997) have shown that it is a gradual and incomplete process where a segment may lose part of its voice feature but also retain enough to avoid neutralization as will be discussed in the following section.

2.3.2.2 Voicing in stop consonant sequences

In the production of consonant sequences, different voicing patterns emerge as a result of the different voicing features of the consonants involved. In English, there are five patterns of voicing in the production of consonant sequences (Docherty 1992). These are illustrated in figure 2.5 as follows: In a sequence where C1 is voiced and C2 is voiceless, both consonants may retain their voicing (1). However, C1 may be totally (2) or partially devoiced (4) as a result of regressive voice assimilation, or C2 may be totally (3) or partially voiced (5) as a result of progressive voice assimilation. Furthermore, the reverse will occur if the voicing of the consonants involved is switched. In a sequence where C1 is voiceless and C2 is voiced, both consonants may also retain their voicing (6). However, as in the previous voice combination, C1 may be totally (8) or partially (10) voiced as a result of regressive voice assimilation, and C2 may be totally (7) or partially (9) devoiced as a result of progressive voice assimilation. This can be illustrated in Figure 2.5 below:

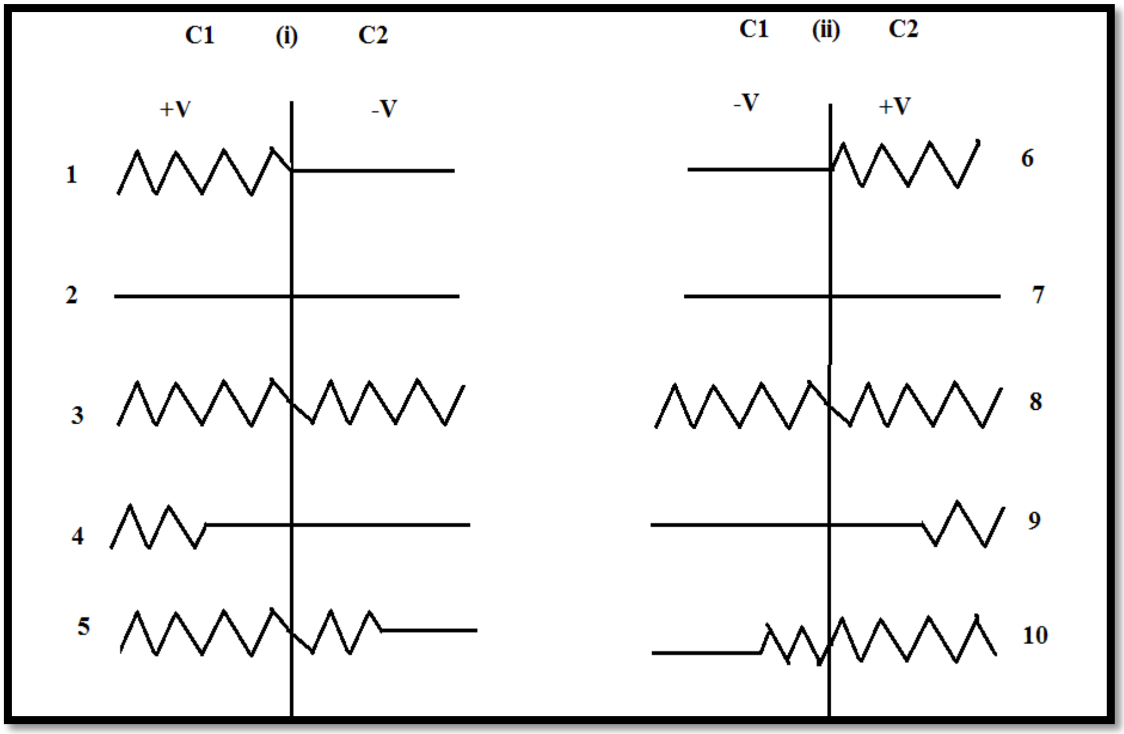


Figure 2.5 Voicing patterns in English consonant sequences (Adopted from Docherty 1992:41)

In some languages, obstruent clusters have only one laryngeal configuration. In languages such as Catalan, Polish, and Russian, the first constituent of an obstruent cluster must agree in voicing with the following constituent. An underlying voiced obstruent C1 becomes voiceless before a voiceless C2 obstruent whereas an underlying voiceless obstruent C1 becomes voiced before a voiced obstruent in C2 (Jun 2011). These are known as 'harmonic' clusters, because the laryngeal quality remains constant across the cluster (Chitoran 1998). Harmonic clusters such as *act* and *apt* also occur in English which is the reason why the plural and past tense suffixes have different allomorphs as in *cats*, *dogs*, and *wished*, *robbed.* However, Heselwood (2007:174) states than in cases where non-harmonic clusters occur in English, the cluster is always broken up by inserting an epenthetic schwa vowel.

Although the laryngeal quality, i.e. voicing, remains constant across these clusters, studies have shown that there are actually two laryngeal abduction and adduction gestures occurring. Lofqvist & Yoshioka (1981) investigated laryngeal activity during the production of voiceless obstruents in Icelandic. They found that in a cluster of two voiceless consonants at normal speech rate, two independent laryngeal gestures occurred, one for each consonant. However, they also noted that as the speaking rate increases, these gestures slide on top of each other resulting in a single laryngeal gesture. Similarly another study was carried out by Lofqvist & Munhall (1992) focusing on laryngeal coarticulation across word boundaries in English which used transilluminaion and fiberoptic video recording of laryngeal activity during the production of the phrase *kiss Ted* at different speech rates. At faster speech rates they observed only a single glottal opening movement for /s/ and /t/ whereas in slow speech rate, two separate glottal openings were found. In other words, the closure duration of the glottis between the two glottal openings for /s/ and /t/ decreases as speech rate increases and eventually becomes zero in an indication that one laryngeal gesture is made for the /s#t/ cluster. Lofqvist & Munhall (1992) concluded that at normal speech rates, two laryngeal gestures occur, the glottis being generally closed between the two.

In other languages including Dutch, German, Polish, Russian, and Catalan, syllable-final voiced stops undergo a complete devoicing process known as neutralization or final devoicing. For example, in Dutch final obstruents are voiceless when occurring in utterance final position but are often voiced when followed by vowel-initial enclitics (Jansen 2004:72). Furthermore, according to Kulikov (2011), voiced obstruents in Russian also undergo devoicing when they occur in word-final position. He also adds that the voicing is retained when followed by another segment. The following examples are from Kulikov (2011:2):

/dub/	[dup]	*oak* (*nom.sg.*)	/duba/	[duba]	(*gen.sg.*)
/sad/	[sat]	*orchard* (*nom.sg.*)	/sada/	[sada]	(*gen.sg.*)
/lug/	[luk]	*meadow* (*nom.sg.*)	/luga/	[luga]	(*gen.sg.*)
/voz/	[vos]	*cart* (*nom.sg.*)	/voza/	[voza]	(*gen.sg.*)

However, as stated earlier, others argue that word-final devoicing process is incomplete (Burton & Robblee 1997) and therefore resulting in voice assimilation being gradual. In their acoustic study of voicing assimilation in Russian, Burton & Robblee found that voicing assimilation is usually regressive in Russian. In their study of voicing assimilation across a preposition+word boundary C#C, C1 of the stop and fricative sequences in /z#d, s#d, z#t, s#t/ and /d#z, t#z, d#s, #ts/ was measured in terms of closure/fricative duration in addition to the duration and amplitude of voicing. Their results reveal that there was more voicing of C1 in the /zt/ sequence than in the /st/ sequence therefore suggesting incomplete devoicing. In addition, less voicing was found in C1 of the /sd/ sequence than in the /zd/ sequence. They claim that voicing neutralization in Russian is partial since the devoicing and voicing of C1 in both examples respectively was incomplete.

In the above study, it can be noticed that C1 and C2 of the sequences investigated shared the same place of articulation. However, it has been argued that other features may interfere with voice assimilation. In their study investigating assimilation between stops across the word boundary in four dialects of Jordanian Arabic, Zuraiq & Abu-Joudeh (2013:75) argue that if adjacent segments differ in other features such as place in addition to voicing, voicing assimilation is blocked as observed in /hubb#faani/ [hub faani] '*a fading love'*. Voice assimilation between C1 and C2 occurs on the condition that C1 assimilates in place to C2 as in /zet#baladi/ [zeb baladi] '*local oil'*. Given that place assimilation only occurs when both C1 and C2 are oral stops, this observation is in line with the generalization that voicing assimilation only occurs when all other surface features of the two consonants are identical.

Furthermore, speech rate has also been found to provide an environment in which assimilation becomes obligatory. However, Kulikov (2011) has argued that an increase in speech rate does not affect the results of voice assimilation directly. In his study, Kulikov examined voice assimilation across the word boundary in Russian with the aim of determining whether voice assimilation takes place in obstruent-obstruent clusters across a word boundary at different speech rates. His data consisted of eight obstruent-obstruent combinations in which C2 was voiceless /pt/, /tp/, /kp/, /sp/, /bt/, /dp/, /gp/, /zp/, and eight obstruent-obstruent combinations in which C2 was voiced /pd/, /tb/, /kb/, /sd/, /bd/, /db/, /gd/, /zd/. Results from his study reveal regressive voice assimilation across the word boundary in Russian but suggest that speech rate does not directly affect voice assimilation. Kulikov notes that voicing in C1 does not increase in normal and fast speech before a voiced C2 or more voiceless before voiceless C2. The only effect of speech rate was found in the relationship between closure duration and voicing duration where in slower speech rates resulted in an increase in duration of both closure duration and voicing in the voiced consonants, but voicing duration in voiceless consonants remains stable across speech rates.

Teifour’s (1997) study of voice assimilation in Syrian Arabic found that regressive voice assimilation occurs across the word boundary in this language. More specifically, Teifour found that both regressive voicing and regressive devoicing assimilation spreads across the word boundary, as shown in the following examples from the study:

/ʃtre:t#da:r/	[ʃtre:d da:r]	*I bought a house*
/walad#ta:ni/	[walat ta:ni]	*another child*

Voice assimilation also occurs in TLA. According to Elgadi (1986) regressive voice assimilation in TLA occurs when the voiceless second person singular prefix /t/ assimilates to the voiced C1 of the verb stem and can be found in the following examples:

/tzi:d/	[dzi:d]	*you add*
/tgu:l/	[dgul]	*you say*

However, thus far, voice assimilation across the word boundary in TLA has not been thoroughly investigated. Therefore, the, stops adjacent to the word boundary of the tokens in TLA investigated in this study consist of four voice combinations, two combinations with voice agreement and two combinations with voice disagreement, which will provide possible assimilation sites:

i- Voiced-voiceless as in /ʃid#tal/
ii- Voiceless-voiced as in /ʒit#giʃ/

The word boundary in both examples in (i) and (ii) are possible assimilatory sites since both stops disagree in voicing. This provides an excellent testing ground for investigating voice assimilation across the word boundary in TLA. For example, in the token /ʃid#tal/ C1#C2, would C1 be the trigger and C2 the target as in progressive voice assimilation or vice-versa as in regressive voice assimilation. The effect of speech rate on voice assimilation will also be investigated by measuring the duration of voicing/voicelessness in the target segment in normal and fast speech rates. Furthermore, in addition to voice disagreement across the word boundary between C1 and C2, some of the tokens also disagree in their place of articulation as in the token /dag#tal/. The claim put forward by Zuraiq & Abu-Joudeh (2013) that voicing assimilation is blocked if both consonants do not share all other features will also be tested for TLA by using these examples.

2.4 Articulatory Phonology

Various theoretical frameworks have analyzed the coproduction of consonant sequences. Unlike the feature-based model of speech production (Daniloff & Hammarberg 1973) which assumes that coproduction and coarticulation is the result of the spreading of a feature of one segment to an adjacent segment, in the Articulatory Phonology model, gestures, and not features, are considered to be the underlying cognitive linguistic units. Fowler & Saltzman (1993:172) define phonetic gestures as "linguistically significant actions of structures of the vocal tract".

The Articulatory Phonology model was proposed by Browman & Goldstein (1986, 1988, 1989, 1990, 1992) in order to describe processes such as coarticulation, epenthesis, assimilation, and deletion. In Articulatory Phonology, gestures represent the discrete physical events taking place during speech production (Browman & Goldstein 1992). In this model, speech is described in terms of how the gestures are coordinated with each other.

In Articulatory Phonology, gestures are characterized by variables that refer to both the location and degree of constriction in the vocal tract. (Davidson 2003:7). According to Browman & Goldstein (1992:156) task dynamics has been used to account for coordinated actions involving more than one articulator. In speech, these tasks involve the formation of various constrictions at different locations in the vocal tract relevant to a particular language. One aspect of task dynamics is the motion of tract variables, which characterizes a dimension of vocal tract constriction, and not the motion of individual articulators that is characterized dynamically. For example, a lip aperture (LA) tract variable is affected by actions of the upper and lower lip in addition to the jaw. Five tract variables are identified: Lips (L), Tongue Tip (TT), Tongue Body (TB), Velum (VEL) and Glottis (GLO) (Figure 2.6).

Furthermore, Davidson (2003) adds that in this model of speech production, each of these articulators is independent of the other, and therefore allows for a separate gestural representation for each variable. In order to account for the fact that tract variables can constrict the vocal tract in several positions, these tract variables are specified for constriction locations (CL) which include [protrusion], [labial], [dental], [alveolar], [postalveolar], [palatal], [velar], [uvular], and [pharyngeal]. Furthermore, constriction degree (CD) is used to distinguish between various constrictions that can be formed at the same location. These include [closure] for stops, [critical] for fricatives, and [narrow], [mid], and [wide] for vowels and approximants.

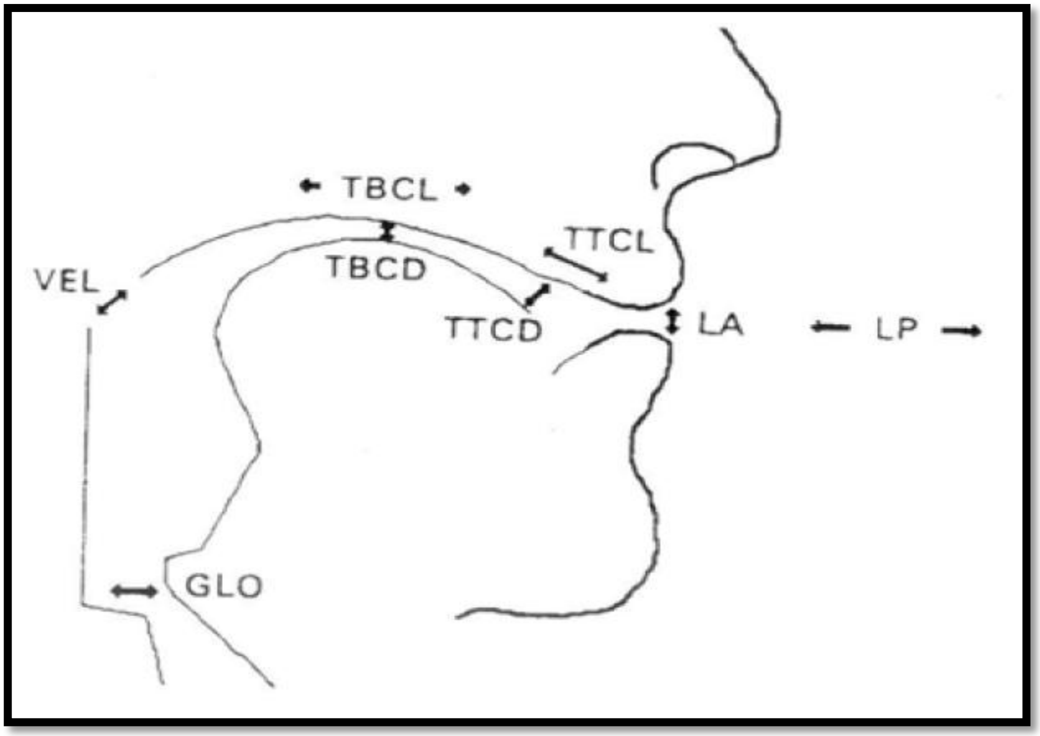


Figure 2.6 Tract variables and associated articulators (from Browman & Goldstein 1990:344)

Gestures are dynamic units, which, unlike features, are allowed to overlap in time. According to the theory, and due to their intrinsic temporal structure, gestures can overlap in time with adjacent gestures during the speech process. ‘Since gestures have internal duration, they can overlap with each other; and since gestures are physical events, they are affected by physical processes occurring during the act of talking’ (Browman & Goldstein 1992:160).

This model has been adopted in more recent studies (Gafos 2002, Byrd and Saltzman 2002, Davidson 2003, Hall 2003) investigating gestural coordination and the timing relations between gestures in addition to factors that influence these relations. These will be discussed elsewhere (see section 2.4.2). In these studies, a gesture is considered ‘a spatio-temporal unit, consisting of the attainment of some constriction at some location in the vocal tract’ (Gafos 2002:270). Gestures in this study are considered to be phonetic events in addition to being dynamic units, the state of which changes over time.

Gafos (2002) states that as a gesture unfolds, it is possible to identify a set of states that he calls landmarks and which constitute the internal temporal structure of a gesture. Gafos adds that gestures enter into temporal relations of overlap that refer to these landmarks. In his description of a gesture, Gafos (2002:276) identifies five landmarks: The first landmark is the ONSET (1) which refers to the moment of active movement of the articulator towards the target of the gesture. The second landmark is the TARGET (2) which refers to the point in time when the articulator reaches the target. The third landmark is the C-CENTER (3) which is the midpoint of the gestural plateau and is between the articulator attaining the target and the release. During this phase the articulator reaches maximum contact. The fourth landmark is the RELEASE (4) which refers to the onset of the movement of the articulator away from the target. The fifth and final landmark in a gesture is the RELEASE OFFSET (5) referring to the point in time when active control of the gesture ends (figure 2.7). Gafos points out that these landmarks comprise the internal temporal structure of a gesture. During the production of consonant clusters in connected speech, adjacent segments have an articulatory effect on each other and the timing and duration of the gestures varies. The degree of gestural coordination can account for processes such as coarticulation, assimilation, epenthesis and vowel intrusion, and deletion.

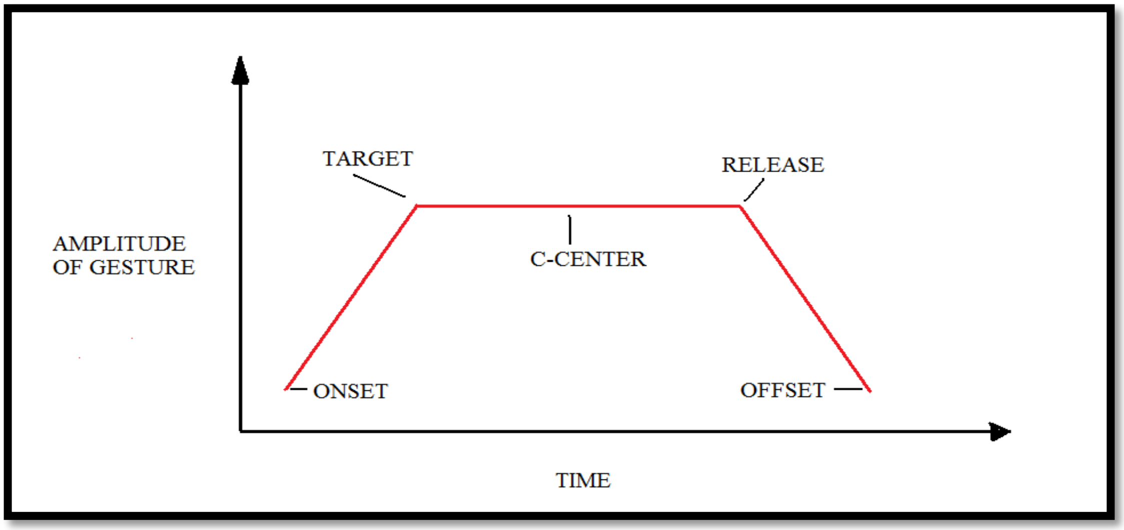


Figure 2.7 Gestural Landmarks adopted from Gafos (2002:276)

In line with recent works by Gafos, Byrd, and Hall, this study adopts the view that gestures are concrete articulatory movements within the framework of Articulatory Phonology. Viewing gestures from this perspective will facilitate the description of processes such as gestural coordination, assimilation, and epenthesis.

2.4.1 Gestural phasing and coordination

The above discussion focuses on describing gestures as individual events that are isolated and independent of neighbouring articulatory context. But during the production of consonant sequences in connected speech, adjacent segments have an articulatory effect on each other as a result of coarticulation. In connected speech, coordination relationships between gestures govern the timing of gestures such that one gesture may begin at a point where another gesture has reached its target or being released. Gestural coordination is ‘a relation between two gestures stating that a specified landmark (within the temporal structure) of one gesture is synchronous with a specified landmark of another gesture’ (Gafos, 2000:277). Within the gestural framework of Articulatory Phonology, gestures are organized in time and space. Articulatory timing is considered as the timing pattern responsible for organizing gestures in speech. Gestures are temporally coordinated with each other and due to their intrinsic timing; gestures can overlap during speech (Browman & Goldstein 1989).

These intergestural timing relations are also referred to as ‘phasing relations’ where they exist between adjacent vowels, and between vowels and preceding and following consonants, and between consonants in sequences (Byrd 1992:4). Byrd points out that these relationships allow gestures to overlap spatially and temporally resulting in an acoustic output which varies according to the behavior of active gestures. In these timing relations, gestures are realized with respect to the internal states of other gestures.

Coordination relations between adjacent gestures can be described as being either in close transition or in open transition (Catford, 1988:116). Catford defines close transition as the formation of the articulatory stricture of the second consonant in a C1C2 cluster before the stricture of the first consonant is released. In other words, close transition refers to the HP being maintained throughout both consonants of the sequence. On the other hand, open transition refers to the situation where there is a release of the HP of C1 before the closure of C2 resulting in a period of open oral tract.

Gestural overlap results from specific coordination relations between gestures. According to Gafos et. al (2010:658), the temporal relations of overlap between gestures of different segments is achieved through these coordination relations. Gafos (2002) points out the importance of articulatory timing in consonant sequences where a landmark in the temporal structure of one gesture may be synchronous with a landmark within the temporal structure of another gesture thus resulting in gestural overlap. In terms of gestural coordination, Gafos *et. al* (2010) state that different gestural coordination relations imply different degrees of overlap between gestures. In the production of consonant clusters, it is possible to identify three distinct gestural coordination patterns (Figure 2.8). In relation to gestural landmarks in figure 2.7, in the first coordination pattern (a), the two gestures are produced with some degree of overlap but with an intervening acoustic release resulting in a period of open oral tract. In this type, the onset of movement for the second gesture is initiated around the mid-point of the c-center stage of the first gesture cc=o. As for the second gestural coordination pattern (b), here no overlap occurs between both gestures. The onset of movement for the second gesture is initiated during the release offset stage of the first gesture roff=o. This timing pattern results in the production of an acoustic release of the first gesture resulting in a longer open oral tract period and no overlap. Finally, in the third gestural coordination pattern (c), the gestures are more overlapped than in (a). Here the onset stage of the second gesture is initiated at an earlier stage during the c-center of the first gesture and therefore the target stage of the second gesture is reached as the release stage of the first gesture is about to be initiated resulting in more gestural overlap and therefore no acoustic release is present r=t. The main difference between type (a) and

(c) is that the degree of gestural coordination is weaker in (a) resulting in a period of open oral tract although there is a relative degree of overlapping.

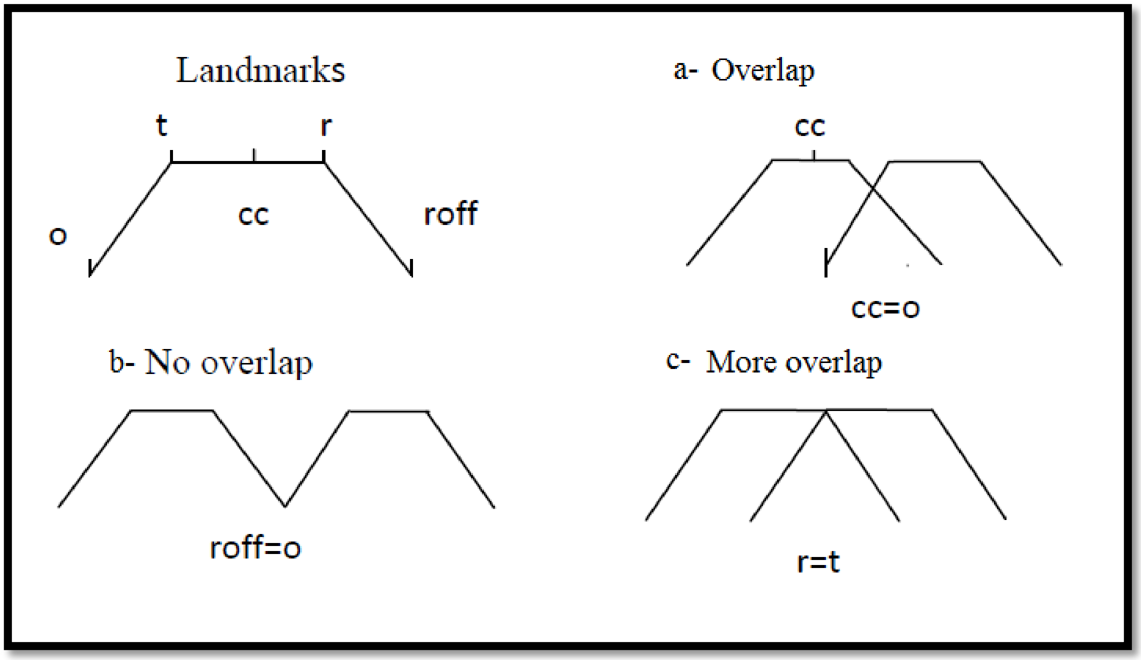


Figure 2.8 Gestural coordination relations adopted from Gafos (2010:658)

From the above illustration it can be seen that the acoustic release of the HP of the first gesture in both (a) and (b) can be considered as an open transition between the two gestures. On the other hand, in type (c), there is close transition between the gestures due to the absence of the acoustic release and therefore resulting in the total overlapping of gestures. However, although both coordination patterns resulted in an acoustic release of the first gesture, the temporal relation between gestures in (a) and (b) differed resulting in a shorter open oral tract interval in (a) and therefore the gestures are relatively in close coordination and tighter gestural coordination. The absence of the release burst in (c) signals total gestural overlap and therefore a higher degree of gestural coordination.

The period of open transition resulting from the lag between gestures also leads to the production of a schwa-like vocalic element to occur between the gestures (Gafos et. al 2002:14) as a result of epenthesis. Most of the literature uses the term epenthetic vowel in reference to this type of vowel. However, others have used the term 'excrescent' (Gafos 2002; Gick & Wilson 2006) vowels. A distinction between epenthetic and excrescent vowels is crucial in this study in accounting for gestural coordination of stop sequences across word boundaries in TLA. The patterns of epenthesis in consonant sequences in addition to the difference between epenthetic and excrescent vowels resulting from different types of gestural coordination patterns will be addressed in section 2.5. For the meantime, since occurring between two consonants, this vocalic element which is a non-lexical vocalic element is referred to as an 'inter-consonantal interval', henceforth ICI.

Furthermore, timing relations governing the coordination patterns between gestures are also influenced by several factors. 'The coordination relation demands a particular timing relation that may or may not produce an acoustic release depending on the nature of the two consonants and other parameters such as rate of speech' (Gafos 2002:16). The degree of gestural coordination also depends on factors such as phonetic environment (Hardcastle & Roach 1979:531). Other factors also include the place of articulation of the gestures involved, and sequence position. These factors will be discussed in further detail in the following section.

2.4.2 Factors affecting gestural coordination

In the following sections, the acoustic and articulatory evidence that various factors have on articulatory timing and the coordination of gestures in stop sequences will be discussed. Phasing relations are subject to factors that influence the degree of coordination between gestures. As previously mentioned, phonetic environment, place of articulation, speech rate, and sequence position have been found to influence inter-gestural timing in stop sequences during their production. Furthermore, a decrease in the degree of gestural coordination in stop consonant sequences can result in the production an ICI which will be further discussed in section 2.5. The effect that these factors have on the gestural coordination of stop sequences has been investigated in several languages within the theoretical framework of Articulatory Phonology. These languages include Moroccan Arabic (Gafos 2002); Georgian (Chitoran 2002); English (Browman & Goldstein 1998) and (Byrd1996); Russian (Zsiga 2000, 2003), and English (Byrd & Tan 1996).

2.4.2.1 The effect of sequence position

One of the main factors that influence articulatory timing between gestures in stop sequences is the position of the sequence being either SI, SF, word-medial, and across word boundaries. Several studies have demonstrated that gestural coordination in SI differs from SF stop sequences where SI sequences exhibit less gestural overlap and higher rates of acoustic releases of C1 in comparison with SF sequences (Chitoran 2002: Wright 1996). In his acoustic study of SI and word medial stop sequences in Tsou, Wright (1996:76) states that C1 release in SI sequences were 100% whereas they averaged 54% in word-medial stop sequences.

These variations in the articulatory timing and gestural coordination of different sequence positions have been explained in terms of perceptual recoverability. In SF position, listeners have access to transitional cues into C1 from the preceding vowel. However, due to the absence of transitional cues into C1 of the SI sequence, gestural overlapping of consonants in this position can threaten their perceptual recoverability. Wright explains that due to perceptual recoverability, stops in positions where transitional cues do not exist are produced with an audible release. Chitoran et al (2002) also add that because of the limitation of acoustic data in C1, the degree of overlapping in SI sequences is restricted to preserve as much acoustic data as possible.

Furthermore, Byrd (2003:11) also points out that SI and SF consonant sequences differ in terms of the coordination relationships between gestures. Timing relationships between gestures in SI position are stable in terms of gestural coordination whereas in SF position, these timing relationships are variable and do not exhibit stability. This view is also held by Gafos (2002). In his investigation of SI and SF consonant sequences in Moroccan Arabic, Gafos found that excrescent vowels resulting from the lag between C1 release and C2 onset in a consonant sequence were found to occur in SF consonant sequences and not in SI sequences where close transition between the gestures occurred. It is worth pointing out that the results of this study differ from the study of Tsou (Wright 1996) and of Georgian (Chitoran 2002) mentioned earlier where results from these studies showed that more C1 releases in the SI consonant sequences of both languages occurred due to perceptual recoverability issues.

The above described variations in gestural coordination patterns are also highlighted by the C-centre hypothesis (Browman & Goldstein 1988: Byrd 1994) which states that SI and SF consonant sequences are organized differently. The c-centre is considered to be the mid-point or centre of the gesture or gestures that make up a cluster (Byrd 1995:286). In SI consonant sequences, Browman & Goldstein (1988) claim that gestures are timed globally and organized with the following vowel by phasing their c-centre to the following vowel. This results in a steady relationship between the c-centre of the SI sequence and the following vowel whether the onset is a singleton or a cluster.

On the other hand, in SF consonant sequences, a steady timing relationship was not found which suggests that the gestures are timed locally with the preceding vowel (Browman & Goldstein 2000). In these clusters, the left-most edge of the cluster is in a stable relationship with the preceding vowel regardless of the number of consonants in the cluster. The differences between gestural coordination patterns in SI and SF consonant clusters as put forward by the C-centre hypothesis can be further highlighted below:

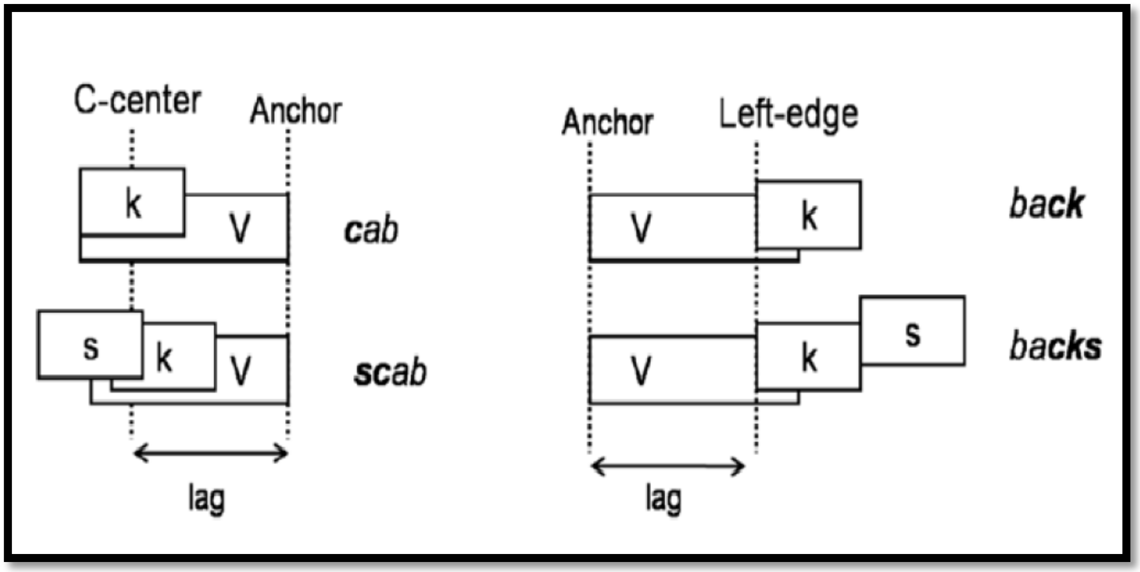


Figure 2.9 C-centre hypothesis for gestural coordination in SI and SF clusters: adopted from Marin & Pouplier (2002:381)

Contrary to SI and SF consonant sequences, the literature shows that articulatory timing relations and gestural coordination patterns across word boundary consonant sequences have not been thoroughly investigated. A fundamental question here is how gestures are coordinated across word boundaries and whether there is closer or looser gestural coordination in comparison to SI and SF stop sequences. In their study comparing gestural coordination patterns across word boundaries C#C in Taiwanese Chinese and American English, Gao et. al (2011:725) reported that there was closer gestural coordination across the word boundary in Taiwanese /tap#kap/ and /tap#tap/ sequences than in American English *top cop* /tɑp#kɑp/ and *cop top* /kɑp#tɑp/ sequences. The results of their acoustic study indicated that there was shorter lag between SF C1 offset and SI C2 onset in Taiwanese than in American English therefore closer gestural coordination in the former. They also point out that cross-linguistic gestural coordination differences show that different languages exhibit different coordination patterns.

Further studies have also shown that gestural coordination patterns across the word boundary can vary. In her study of English and Russian, Zsiga (2000) observed that in C#C stop sequences; there were more C1 releases in Russian than in English, suggesting that Russian exhibits less gestural overlap than English. Zsiga (2000:70) uses two measures of gestural overlap; % of release, the percentage of unmasked releases of C1 in the sequence, and duration ratio where she compared the duration of the cluster to the durations of the two consonants in intervocalic position. She compared gestural coordination across the word boundary in examples such as /k#t/ *make tarts* (Eng.) vs. *pok tort* (Rus.), and /p#t/ *stop tarts* (Eng.) vs. *grop tam* (Rus.) *rowed there*. Results indicate that the percentage of unmasked releases was 47% in Russian C#C sequences compared to 18% in English. In addition, Russian sequences exhibited a longer duration ratio than their English counterparts.

Other studies have also found similar results where gestural coordination was weaker between gestures across word and morpheme boundaries. According to Cho (1998), gestural coordination across word boundaries is weaker than within syllable boundaries: ‘the timing between two gestures within a single lexical entry is specified in the lexicon and it is preserved on the surface. On the other hand, the timing between two gestures created by morpheme-concatenation is not lexically specified, and is therefore potentially subject to any phonological change which can be produced by varying gestural overlap’ (Cho 1998:15).

Cho (2001) argues that lag intervals between gestures within a word or morpheme seem to be shorter than across word or morpheme boundary and that these shorter intervals that are associated with a single lexical entry indicate that the gestures are more strongly bonded. As a result, the stronger bonding for gestures within a lexical entry would result in greater stability in intergestural timing as opposed to the weak bonding of gestures across different lexical items (Figure 2.10).

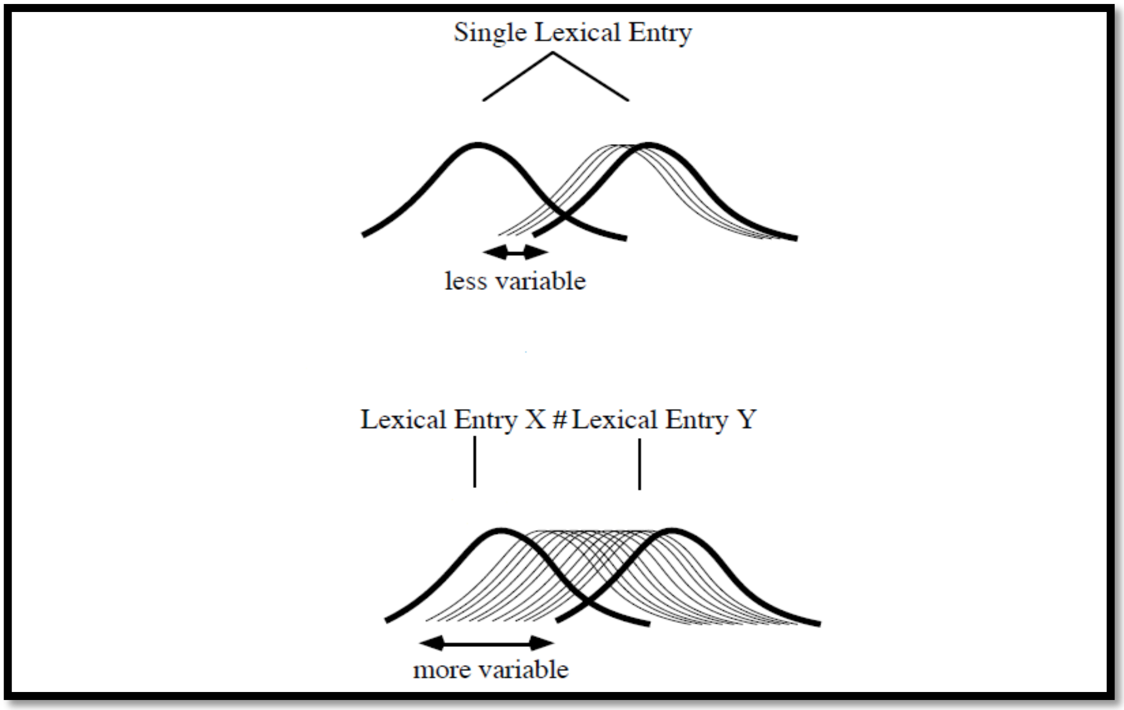


Figure 2.10 Variability in articulatory timing between gestures within a single lexical entry and across morpheme or word boundary (#): from Cho (1998)

It is also worth pointing out that these studies only focus on gestural coordination patterns across word boundaries in C#C sequences. To the best of my knowledge, there are no studies investigating the effect of an increase in the number of stop consonants across the word boundary as in CC#C, C#CC, and CC#CC sequences on gestural coordination across the word boundary which is the main focus of this study.

2.4.2.2 The effect of place order of gestures involved

The effect of place order of consonants in a sequence, the anterior-posterior location of C1 constriction in relation to C2 constriction, has also been found to influence the articulatory coordination patterns between gestures. Studies have shown that the degree of gestural coordination differs between front-to-back and back-to-front place order (Hardcastle & Roach 1979); (Byrd & Tan 1996); (Zsiga 2000, 2003); (Kochetov 2007). Most of these studies have shown that front-to-back consonant clusters exhibit closer gestural coordination than in back-to-front clusters. Some have explained this from an articulatory point of view. Hardcastle & Roach (1979:34) argue that in English, closer gestural coordination is exhibited in a front-to-back place order /tk/ cluster than in a /kt/ cluster. They claim that this is due to the anatomy of the tongue. They concluded that the movement of the tongue in a /tk/ cluster involves the contraction of a single intrinsic tongue muscle to raise the back of the tongue to create the closure for the TB /k/ gesture and therefore closer gestural coordination. On the other hand, the movement in a /kt/ cluster requires the use of two muscles including the extrinsic genioglossus to move the tongue upwards and forwards to create the closure for the TT /t/ gesture. This requires more time and therefore less gestural coordination is exhibited between gestures in a back-to-front place order of articulation.

However, some have argued that this gestural coordination pattern is language specific. In her study comparing patterns of gestural coordination across word boundaries in English and Russian, Zsiga (2003) found that in Russian there was closer gestural coordination and less gestural lag between consonants in front-to-back sequences than in back-to-front. As for English, Zsiga states that no significant difference in gestural coordination between both place orders was found in English.

In a study investigating cross-linguistic differences in gestural overlap in stop consonant clusters in Russian and Korean, Kochetov et. al (2007) also investigated the effect of place order in both languages. The tokens used in this study comprised of /kp/ /kt/ and /pt/ stop clusters in both Russian and Korean. In this study, the degree of overlap between stop gestures was measured in terms of gestural lag. This was calculated as the time between the release of C1 and the achievement of target for C2. In general, Russian speakers exhibited greater plateau lag, less overlap, than Korean speakers where the average difference was about 35ms. As for the effect of place order, results showed that shorter gestural lag and therefore closer gestural coordination was exhibited in both languages in the /pt/ cluster than in the /kp/ and /kt/ clusters where C1 closure was anterior to C2 closure. Kochetov et. al. (2007:1363) claim that these effects are the result of two factors. One of the reasons may be due to recoverability constraints. Perceptual factors influence language-particular grammatical constraints on gestural coordination, resulting in different timing patterns for front-to-back and back-to-front clusters. They also add that in the /kt/ consonant cluster, the same articulator is used for both consonants of the cluster. Therefore, the tongue tip movement towards the target for /t/ is constrained by the tongue dorsum/k/ gesture, resulting in more gestural lag between the two closures and therefore less gestural overlap.

The same results were also noted by Chitoran *et. al* (2002). In their study they investigated the effect of place order on gestural coordination in Georgian stop clusters in both SI position and word medial position. The results of this study show a significant effect of place order on gestural coordination. In the front-to-back stop sequences, C2 onset occurs with less gestural lag on average after 3% of the C1 constriction interval. On the other hand, in the back-to-front sequences, C2 onset occurs after 82% of the interval therefore exhibiting more gestural lag. Chitoran et al. (2002:19) state that stop sequences with a front-to-back order of place of articulation show significantly more overlap than sequences with the back-to-front order of place of articulation. They claim that recoverability considerations constrain the patterns of articulatory overlap. In back-to-front sequences, C2 constriction is more anterior than C1 and therefore the release of C1 will produce no acoustic manifestation if the constriction for C2 is already in place. As a result, back-to-front sequences allow less overlap in order to avoid the loss of the acoustic information in the release of C1. On the other hand, in front-to-back sequences where C2 constriction is more posterior to C1 constriction, at least some acoustic information will be generated on the release of C1 constriction even if there is a high degree of gestural overlap. However, they also point out that a significant interaction is found between the effect of place order and sequence position. The effect of place order was significant in SI position and not in medial position.

In this study, place order effects on gestural coordination across the word boundary will be investigated in TLA. However, since the stops under investigation consist of alveolar and velar stops /t,d,k,g/ involving a TT and a TB gesture, the anterior and posterior constriction locations are referred to as coronal-dorsal and dorsal-coronal henceforth (CD) and (DC) place order.

2.4.2.3 The effect of speech rate

Many studies have found that changes in articulatory timing and gestural coordination patterns are directly related to changes in speech rate (Hardcastle 1985), (Huinck et al 2004), (Byrd & Tan 1996). As a result of changes in speech rate, gestures can be phased differently with respect to one another (Davidson 2003:174). Several studies have shown that an increase in speech rate results in closer gestural coordination. Using EPG to identify the degree of overlap in the articulatory gestures for /k/ and /l/ in different speech rates, Hardcastle (1985) investigated gestural coordination in /kl/ clusters in five different contexts, '*clock', 'backlog', 'black lock', 'black, lock' and 'black. Lock*'. Hardcastle found that gestural overlap was minimal at slow speech rate in all contexts, whereas closer gestural coordination was exhibited in fast speech rate. Huinck et. al (2004:5) also state that faster speaking rates cause gestures to slide together and as a result greater gestural overlap whereas in slower speech rates, gestures tend to slide further apart resulting in less gestural overlap.

A similar effect of speech rate on gestural coordination was also found by Gafos (2002). In his study of gestural coordination of consonant clusters in Moroccan Colloquial Arabic, Gafos focused on the effect of speech rate on transitional releases between consonants. He points out that the presence or absence of an acoustic release between consonants is dependent on the type of consonants involved and speech rate (Gafos 2002:18). Gafos states that in normal speech rate, heterorganic consonant clusters are produced with an acoustic release, whereas homorganic clusters are not produced with an acoustic release. However, in fast speech rate, the transitional release is not present in homorganic and heterorganic clusters in an indication of an increase in gestural overlap as a result of the increase.

Speech rate has also been found to affect the duration of segments. In his investigation using both acoustic and electromyographic (EMG) data, Gay (1981) indicates that the duration of segments decreases as the speech rate and the velocity of the articulators increases. He also points out that the decrease in segment duration is not uniform where a higher decrease occurs in vowel durations in comparison to the decrease occurring in consonant durations as a result of the increase in speech rate.

Byrd & Tan (1996) also investigated the effect of speech rate on overlap duration in addition to gestural coordination and gestural magnitude of gestures across the word boundary in [d#g], [g#d], [s#g], and [g#s] sequences. Using EPG in their investigation, the sequences were placed in a carrier sentence and recorded in four speech rates, ‘normal’, ‘medium’, ‘faster’, and ‘fastest’ speech rates. Their results indicate significant segment duration differences at different speech rates. They state that the duration of consonants become shorter as speech rate increases. This shortening in duration as a result of the increase in speech rate was also exhibited by consonants that were highly overlapped. Significant differences in gestural coordination were also found between different speech rates. Byrd & Tan (1996:270) point out that temporal coarticulation increased as speech rate increased and also that overall faster speech rate also resulted in greater overlap durations. As for the effect of speech rate on gestural magnitude, maximum contact percentages in the front and back regions for both consonants of each sequence was examined. The results exhibited a strong effect of speaking rate on gestural reduction where gestural magnitude decreased as the speech rate increased. However, this reduction was more consistent in SF consonants than in SI consonants. Furthermore, Byrd & Tan also add that this reduction in magnitude was more evident in stops than in fricative /s/.

Speech rate has also been found to have an effect on laryngeal gestures (Munhall & Lofqvist 1992). Using transillumination and fiberoptic video recording to record laryngeal abduction-adduction movements, Munhall & Lofqvist investigated the temporal overlap of laryngeal gestures across the word boundary in the phrase *kiss Ted.* The results from this study show that two separate glottal gestures were found at slow speech rates with each consonant retaining its own glottal gesture. However, at faster speech rates, only one glottal gesture was observed for the two intervocalic obstruents.

They argue that the single glottal gesture is a result of greater consonant overlap and blending of the glottal gestures (1992:122).

2.4.2.4 Summary

This section summarized the main factors affecting gestural coordination. The factors discussed were the effect of sequences position, place order, and speech rate. SI, SF, and across word boundary sequences have been found to exhibit different gestural coordination patterns. Tighter gestural coordination patterns and shorter ICI durations as a result of shorter lag intervals between gestures have been exhibited more in SI sequences in comparison to SF and across word boundary sequences. The place order effect on gestural coordination has also shown varying gestural coordination patterns based on the location of C1 constriction relative to C2 constriction in a sequence. Shorter lag intervals have been found in front-to-back place order compared to back-to-front place order where a higher probability of vowel epenthesis was found. This has been explained in terms of the speed and velocity of the articulators involved. However, another reason is due to perceptual recoverability. As for the effect of speech rate, not only does it have an effect on gestural coordination, it has also been shown that segment durations are also affected. An increase in speech rate results in the decrease of segments. This increase also resulted in the decrease of transitional releases between gestures and therefore less epenthesis and also an increase in the overlap period. As a result, shorter ICIs occur in faster speech rates. Although these are not the only factors influencing gestural coordination between stops, they are the main factors investigated in this study.

2.5 Types of inter-consonantal intervals

As previously mentioned in section 2.3.3.1, specific gestural coordination patterns where a lag interval occurs between gestures results in the production of a vowel-like ICI. The intrusion of the ICI between gestures is generally referred to as epenthesis. Furthermore, most of the literature uses the term epenthetic vowel in reference to this type of vowel. However, studies in Articulatory Phonology have identified different types of vowel intrusion; epenthetic vowels (Browman & Goldstein, 1992, 1995); and excrescent vowels (Gafos 2002; Gick & Wilson 2006). Generally speaking, epenthetic vowels result from a phonological process where an ICI occurs as a result of an actual vowel being inserted by speakers when faced with problematic combinations. On the other hand, excrescent vowels result from the misalignment of two adjacent gestures. Specifically, when the two gestures are not sufficiently overlapped in production, the resulting ICI between the two gestures yields a vowel like transition between consonants. The main features of both these types will be presented in sections 2.5.1 and 2.5.2.

The process of vowel epenthesis refers to any process in which a vowel is added to an utterance (Hall 2011:1576). This process usually occurs in many languages in problematic consonant clusters or clusters that do not conform to the phonotactics of a specific language. In Spanish, for example, phonotactic restrictions prohibit the occurrence of SI clusters of the type /s/ + stop (Hickey 1985:233). As a result, epenthetic /e/ is used resulting in *escuela* ‘school’ which differs from Italian *scuola* ‘school’ where /s/+stop clusters are not prohibited. The process of epenthesis occurs in Dutch and Irish but only in SF position. For example, arm is produced as /ɑ.rəm/ in Dutch and /arəm/ in Irish (Hickey 1985:234).

Although several studies have assumed that the inserted vowel used in epenthesis is usually a schwa [ə], others have claimed that the quality of the epenthetic vowel is language specific. According to Uffmann (2006:1080) the inserted vowel during the process of epenthesis is the default vowel of the language. In Lebanese Arabic for example, Haddad (1984) quoted by Hall (2011:133) states that the default epenthetic vowel is /i/ as in /libs.na/ *our clothing* [libisna] whereas it is /e/ in Farsi (Shademan 2002). In English and German the schwa vowel /ə/ is used for epenthesis. Uffmann states that the default vowels that are applied by languages in epenthesis are phonetically shortest and least salient. However, others disagree with this claim and argue that the quality of the epenthetic vowel varies across speakers. In her study of the quality of epenthetic vowels in Lebanese Arabic, Hall (2013:142) found variation between epenthetic vowels by different speakers. She reports that some speakers produced an epenthetic vowel quality similar to lexical [i] whereas some applied epenthetic schwa [ə].

Studies in L2 acquisition have also shown that L2 learners adopt epenthesis as a strategy when faced with L2 consonant clusters that do not exist in their native language. In her study of Egyptian and Iraqi learners of English, Broselow (1983:271) reported that speakers of these Arabic dialects applied epenthesis to SI English consonant clusters that did not exist in their L1. In the case of the Egyptian learners, an epenthetic vowel was inserted in SI clusters as in *plastic* [bilastik]. On the other hand, Iraqi learners inserted an epenthetic vowel before the SI cluster as in *study* [istadi]. Broselow claims that the different epenthesis sites are a result of transfer of a phonological rule from the first language of both learners.

Furthermore, sonority also plays a role in triggering epenthesis as previously stated in section 1.6.3 where it was argued that in TLA, the three stop SI cluster in /nftaħ/ *it opened*, and /ltħam/ *he welded* violate sonority. Ohala (1999:400) claims that sequences of consonants are preferred over others because of the Sonority Sequencing Principle (SSP). SSP requires that between any element on the edge of syllables and the vowel, only consonants that are higher in sonority than the peripheral consonants are permitted (Figure 2.11). In other words, in a SI cluster CC, sonority of C1 has to be lower than or equal to that of C2. On the other hand, in a SF cluster CC, C1 sonority has to be equal to or higher in sonority than C2.

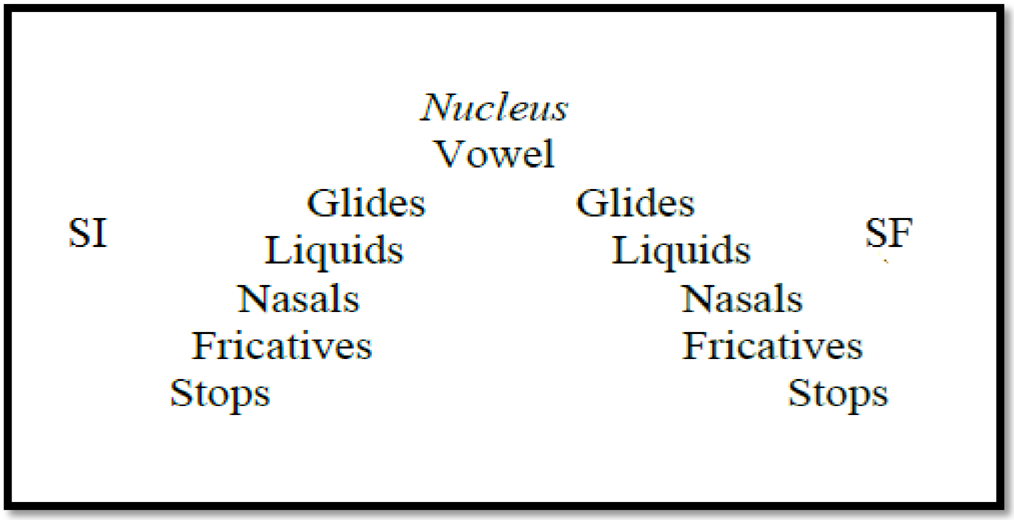


Figure 2.11 SSP in SI and SF consonant clusters (adopted from Carlisle 2001:4)

Constraints on which consonants occur in sequence in the English syllable are further highlighted by Kreidler (1997:91). Kreidler points out that these constraints are determined to a large extent by the sonority scale. He claims that when two consonants occur in a sequence, they follow the scale of sonority, i.e. an obstruent+sonorant or a nasal+glide and that the reverse of these sequences is impossible. This is also stated by Heselwood (2007:160) who adds that sonority is an important constraining factor in syllable structure. However, Heselwood also points out that in many languages including English, sonority violating SI and SF sequences do occur as in the English examples *stops* and *skids* where the more sonorant consonant precedes the less sonorant consonant. In L2 acquisition, these clusters are considered problematic for learners whose native languages do not allow violations of sonority in syllable configurations. This would also lead to the assumption that syllables that do not conform to SSP will most likely be affected by epenthesis.

However, the argument here is whether epenthesis is actually a phonological process where speakers insert an epenthetic vowel or not. In other words, whether the ICI between the consonants is a result of epenthesis or a by-product of specific gestural coordination patterns where C1 is released before C2 closure is reached. Recent studies have shown that the vocalic element occurring between these consonant sequences is not actually a lexical vowel but is the by-product of the lack of overlap between the gestures of these consonants due to articulatory constraints (Browman & Goldstein 1990; Gafos 2002). In other words, in some cases speakers are not deliberately inserting an epenthetic vowel but may be unable to produce smooth transitions between the gestures of these consonant sequences resulting in looser coordination. Gafos (2002:272) states that during the production of consonant sequences, a period of no constriction in the transition between gestures is identified as a schwa-like vocalic element. In his study of Moroccan Colloquial Arabic, Gafos (2002) points out that in SF clusters as in *katb* 'to write', a schwa-like vocalic transition is found in the coda cluster resulting in /kat$^{\text{ə}}$b/. He points out that it is not a lexical schwa but is a result of gestural conflict.

Davidson & Stone (2004) also investigated whether this vocalic element was a result of the process of phonological epenthesis or due to 'gestural mistiming' that results in the perception of a schwa-like vocalic element. In order to distinguish between the two, the data used for their study consisted of /sC/ and /səC/ SI consonant clusters in English and /zC/ SI consonant clusters in Polish:

English /səC/	**English /sC/**	**Polish /zC/**
succumb	scumb	[zgama]

The participants were native English speakers with no knowledge of Polish. Using ultrasound she compared the tongue movement of the English speakers in the production of [zgama] with /skʌm/ and /səkʌm/. They argue that if the English speakers are repairing the phonotactically illegal SI consonant cluster [zC] by inserting an epenthetic schwa vowel resulting in [zəC], the tongue shape movement will be similar to their production of the English [səC] cluster. However, if the participants were mistiming the gestures in /zgama/, the tongue shape movement in [zC] will be similar to [sC] resulting in a transitional schwa.

The ultrasound images showed that the speakers did not use epenthesis to repair the Polish consonant clusters, but they were unable to employ the appropriate gestural coordination required for their production (Figure 2.12). The Polish SI clusters were produced with a schwa-like vocalic element as in [zəgama] by the English speakers. In the [sk] cluster of *succumb,* evidence of schwa was found in the onset of /s/ where it was produced with a relatively low tongue position due to coarticulation with the low /ə/ vowel. However, in the [sk] cluster of *scum*, the /s/ was produced with a very high tongue position due to coarticulation with the high tongue position of /k/. The tongue shape changes in [zəg] of *zgama* were more similar to those occurring in *scum* where [z] seems to be coarticulating with the high tongue position of [g]. Davidson & Stone claim that if a schwa was present in the [zg] cluster, the tongue body will have a lower starting point in /z/ similar to that of /s/ in *succumb*. Davidson & Stone point out that 'if speakers produce the consonants with an insufficiently overlapping configuration 'mistiming', a transitional vocoid would result between the segments in the clusters' (2004:108).

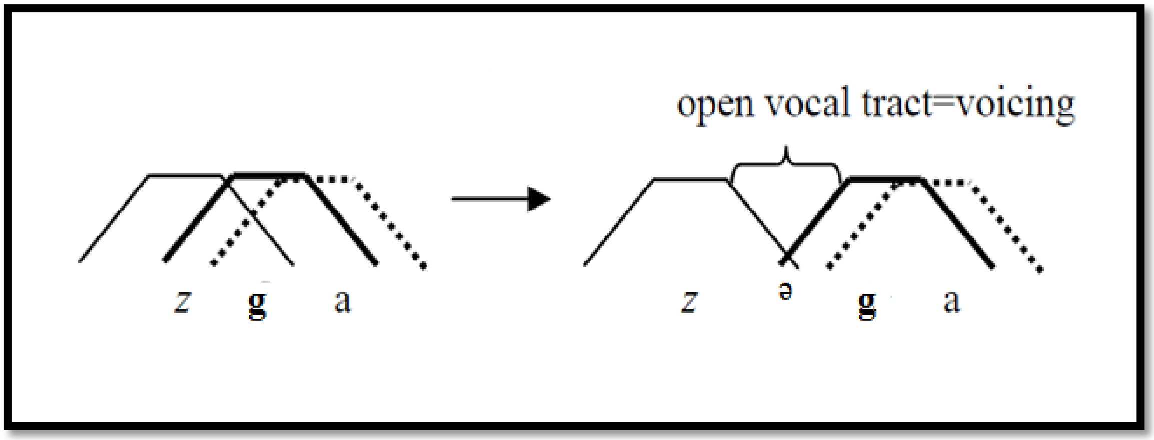


Figure 2.12 Excrescent schwa between consonants with no gesture corresponding to schwa: Adopted from Davidson & Stone (2004:117).

2.5.1 True epenthetic vowels

In the process of phonological epenthesis, the epenthetic vowel produced has an underlying target. In other words, the speaker inserts an epenthetic vowel when faced with problematic or illegal consonant clusters that may be prohibited by phonotactics. These epenthetic vowels are ‘phonological segments inserted in order to repair illicit structures’ (Hall 2006:387). Although being phonological segments with their own gestural targets, epenthetic vowels differ from lexical vowels. In her study of the difference between lexical and epenthetic [i] in Lebanese, Hall (2013) points out that the formants of epenthetic vowels have a higher F1 and lower F2 in comparison with lexical vowels. She also adds that epenthetic vowels have shorter durations than lexical vowels.

The duration of epenthetic vowels are also shorter than lexical vowels. In his study of epenthesis in Spanish consonant clusters, Ramirez (2006) found the duration of the epenthetic vowels were approximately one third the duration of the lexical vowels averaging duration 26.98ms compared to 85.61ms in lexical vowels. Furthermore, Hall (2006:391) points out that duration of epenthetic vowels decreases as a result of an increase in speech rate. In other words, speech rate does not have an effect on the presence or absence of epenthetic vowels.

2.5.2 Excrescent vowels

Excrescent vowels are considered as being a purely phonetic by-product of two conflicting articulatory goals (Gick & Wilson 2006). In their study using ultrasound, they investigated tongue movement from an advanced position to a retracted root/dorsum position in English SI clusters. Results showed that in a front-to-back or back-to-front tongue movement, the tongue is expected to pass through a ‘schwa space’ resulting in the production of a schwa-like vocalic element (Gick & Wilson 2006:650). In such cases, excrescent vowels are a result of conflicting articulatory goals and not true epenthetic vowels that are deliberately inserted by the speaker to break up consonant clusters.

Within the framework of Articulatory Phonology, Browman & Goldstein (1992b) state that the period of time between the two adjacent gestures may produce a transitional schwa, which is underspecified or "targetless". These types of vowels are also phonetically weaker and shorter than other vowels (Hall 2011:1584). Hall (2006) uses the term ‘intrusive’ to refer to these types of vowels. The quality of an intrusive vowel may not exist in the vowel inventory of a specific language. Hall also points out that intrusive vowels result from a vowel gesture in a neighboring syllable gesture which shows through between two adjacent consonant gestures that are loosely coordinated.

Contrary to epenthetic vowels where their duration is only reduced as a result of an increase in speech rate however they still remain, excrescent vowels are likely to be optional, and may disappear at fast speech rates due to an increase of overlap between gestures (Hall 2006:391). Furthermore, excrescent vowels usually occur in heterorganic consonant sequences where articulatory conflict is more likely to occur.

2.5.3 Patterns of epenthesis in consonant sequences

Although epenthesis occurs in many languages in the production of consonant sequences, the pattern of epenthesis, i.e. the position where the epenthetic vowel is inserted in a consonant sequence, is language specific. In most Arabic dialects, and specifically in TLA, CCC sequences only occur as across syllable, word, or affix boundaries. Different languages apply epenthesis in different locations within these problematic sequences. Several studies in Arabic dialects have shown that consonant sequences are broken up by epenthesis in different positions in the sequence.

Kiparsky (2003:147) identifies three different Arabic dialect groups according to the pattern of epenthesis they apply to a CCC consonant sequence:

- C-dialects: these include dialects in Morocco, Tunis, and Mauritania. In addition, Maltese and certain Berber dialects also belong to this type. In this type of dialect, -CCC- consonant sequences are permitted and are not broken up by epenthesis.

- VC- dialects: these include dialects spoken in Syria, Lebanon, Palestine, Iraq, and Eastern Libya. In addition, the dialects of the Eastern part of the Egyptian delta and Upper Egypt also belong to this dialect. In this type, medial -CCC- sequences are syllabified by inserting an epenthetic vowel before the second consonant resulting in -CVCC-.

- CV- dialects: these include most of the dialects of Egypt, the oases of the Libyan Desert, and Middle Egypt. Here, -CCC- consonant sequences are syllabified by inserting an epenthetic vowel after the second consonant resulting in –CCVC-.

In his description of the patterns of epenthesis in different Arabic dialects, Kiparsky cited in Watson (2007:337) further adds that in -CCC- consonant sequences, VC dialects syllabify CCC clusters by epenthesis to the left of the unsyllabified consonant, CV dialects syllabify CCC sequences by epenthesis to the right of the unsyllabified consonant, and C dialects maintain the CCC consonant sequence. It is worth mentioning that in both the VC and CV dialects, the maximum number of consonants that are permitted in a sequence without triggering epenthesis is CC. If the sequence exceeds two consonants, epenthesis intervenes in order to prohibit the formation of three and four consonants in a sequence.

Furthermore, speakers also transfer native epenthesis patterns to their L2 language acquisition process and loanword adaptations resulting in a foreign accent (Broselow 1983). The attempt by learners to bring second language forms to conform to first language restrictions through the process of epenthesis leads to the mispronunciation of L2 consonant clusters. As previously mentioned, Broselow (1983:269) points out that different epenthesis patterns in L2 consonant sequences result from the transfer of a phonological rule from the first language of learners.

To the best of my knowledge, studies of the phonetic characteristics of epenthetic vowels in Arabic dialects are very limited. With the exception of the acoustic study of vowel epenthesis in Lebanese Arabic (Hall 2013), most studies on epenthesis in Arabic dialects have dealt with the process from a phonological perspective within the framework of Optimality Theory.

2.5.3.1 Epenthesis patterns in Egyptian Arabic

Egyptian Arabic is considered an ‘onset’ dialect where in a medial CCC consonant sequence; C2 is syllabified as an onset (Hall 2011:1580). In line with the classification by Kiparsky (2003) and Watson (2007) where Egyptian Arabic is considered a CV dialect, the epenthetic vowel is inserted between C2 and C3. Ito (1989:241) also points out that in Cairene Egyptian Arabic; a CCC sequence is broken up by inserting an epenthetic vowel after C2.

Epenthesis in medial CCC cluster in Egyptian (Ito 1989):

/ʔul-t-l-u/	[ʔul.t[i].lu]	*I said to him*

These epenthesis patterns are dialect specific and differ from other Arabic dialects as will become apparent in the following section. Furthermore, in a 4-consonant sequence CCCC, Ito (1989:241) states that in Cairene Egyptian Arabic, the epenthetic the cluster is broken up in the middle by inserting an epenthetic vowel between C2 and C3.

Epenthesis in CCCC clusters in Egyptian (Ito 1989):

/katab-t-l-ha/	[katabt[i]lha]	*I wrote to her*

As highlighted by Broselow (1983) epenthesis patterns in L2 consonant sequences result from the transfer of a phonological rule from the first language of learners, the same pattern of epenthesis is applied by Egyptian learners of English when faced with consonant sequences in English.

Epenthesis by Egyptian learners of English (Broselow 1983)

Children	/tʃildrən/	[tʃild[i]ren]

In the above English example, the epenthetic vowel [i] is inserted between C2 and C3 of the medial CCC cluster as a result of transfer of the epenthetic pattern from L1.

2.5.3.2 Epenthesis patterns in Iraqi Arabic

In contrast with Egyptian Arabic, Iraqi Arabic differs in terms of the epenthesis patterns occurring in both the native language consonant sequences and English consonant sequences in language learning. In agreement with Kiparsky (2003) and Watson’s (2007) classification of Iraqi as a VC dialect, in a medial CCC sequence, C2 is syllabified as a coda (Hall 2011). In other words, the epenthetic vowel is inserted between C1 and C2.

Epenthesis in medial CCC sequence in Iraqi (Ito 1989):
/gil-t-l-a/ [gil[i]tla] 'I said to him'

However, although applying a different epenthesis pattern in CCC consonant sequences, in the case of CCCC sequences both Egyptian and Iraqi Arabic apply the same pattern. Ito (1989:241) points out that in Iraqi Arabic, a CCCC consonant sequence is also broken up by inserting the epenthetic vowel between C2 and C3.

Epenthesis in CCCC sequence in Iraqi (Ito 1989):
/gil-t-l-ha/ [gilt[i]lha] 'I said to her'

As for L2 acquisition, this language specific epenthesis pattern is found in the production of English consonant sequences by Iraqi learners.

Epenthesis by Iraqi learners of English (Broselow 1983)
Children /tʃildrən/ [tʃil[i]dren]

In the above example, unlike the pattern adopted by Egyptian learners of English, the epenthetic vowel was inserted between C1 and C2.

2.5.4 Summary

This section summarized the main differences between epenthetic and excrescent vowels occurring as a result of epenthesis. ICIs occurring where gestural coordination is weak can be classified as being either epenthetic or excrescent vowels. Epenthetic vowels seem to be applied in order to break up problematic consonant sequences and not allow the formation of consonant clusters exceeding the number of consonants permitted by the phonotactics of a specific language. On the other hand, as highlighted by Browman & Goldstein (1990), Gafos (2002), Gick & Wilson (2006), and Hall (2003), excrescent vowels are merely a by-product of specific gestural coordination patterns due to conflicting articulatory goals. Furthermore, different languages have also been found to apply different epenthesis patterns when inserting epenthetic vowels. This has been highlighted by the examples presented from the Arabic dialects spoken in Iraq and Egypt.

The distinction between epenthetic and excrescent vowels is very important for this study. In order to investigate the production of stop consonant sequences across the word boundary in TLA, resulting ICIs will be investigated in order to determine if they are epenthetic or excrescent type of vowels. The pattern of epenthesis will also be investigated in order to determine if different patterns are applied in the different stop consonant sequence types, C#C, CC#C, C#CC, and CC#CC, that are under investigation in TLA. Furthermore, an interesting question that arises here is how both types of vowels interact with voice assimilation, specifically whether epenthetic and excrescent vowels are transparent to voice assimilation or whether they block the process.

Chapter 3 Methodology

3.1 Introduction

This chapter presents a detailed description of the aim and objective of this study, including its design. Methodological issues, data collection, participants, and instruments adopted are also discussed in this chapter, in addition to how measurements are taken. The first section introduces the research questions that this study will attempt to answer and the rationale for addressing these issues. The second section will describe the participants that took part in this study, including criteria for their selection. Section three of this chapter presents the data that was used in this study in order to answer the research questions in addition to the data collection procedures. In the final section the focus shifts to how the data were analyzed using both EPG and acoustic data analysis in addition to the statistical tests that were carried out in order to address the research questions. The advantages and disadvantages of these methods are also highlighted and how both are equally important in observing and monitoring speech gestures.

3.2 Research questions

The main goal of this study is to provide a description of the interaction between coronal and dorsal stop consonants across word boundaries in TLA. The study focuses on the timing and duration of stop consonant gestures in different environments; -C#C-, -C#CC-, -CC#C-, and finally the -CC#CC- sequence, where # denotes a word boundary. The general aim of this study is to provide a better understanding of speech production and the temporal organisation of articulatory gestures. One of the main characteristics of continuous speech is that speech segments are extremely sensitive to context (Hardcastle et al 1999). The relative timings of lingual-palatal stop gestures as one sound gives way to the next in the stream of speech for different environments across a word boundary was investigated.

As previously mentioned in section 1.3 and 2.4, this study adopts a gestural view of speech production within the framework of Articulatory Phonology as put forward by

Browman & Goldstein (1986), and adopted by Gafos (2002), Byrd & Saltzman (2002), Davidson (2003), and Hall (2003). Being more phonetic than phonological in nature, the notion of ‘gesture’ in this study considers gestures to be concrete articulatory movements, i.e. real movements of the articulators as they can be observed using acoustic analysis and EPG. Viewing gestures from this perspective facilitates the description of gestural coordination and the factors that influence adjacent speech segments such as the number of stop consonants in a sequence, the place order of stops involved, and speech rate. It also assists in investigating processes such as epenthesis, in which a lesser degree of coordination between adjacent segments results in an intervening ICI and voice assimilation across the word boundary and the direction in which it occurs. The main research questions that this study addresses are as follows:

1- What effect does an increase in the number of stop consonants in a sequence have on the timing and duration of stops?

Research question 1 has been prompted by the discussion in section 2.2. It can be anticipated that an increase in the number of stops across word boundary sequences will have an effect on the duration of stops immediately adjacent to the word boundary. Following the studies by Flege & Port (1981) and Shaheen (1979), HP was used for the durational measurements. For example, in a two-stop sequence such as C#C, it is anticipated that the duration of the HP of the SF single articulatory gesture stop C1 stop and SI C2 onset singleton would be affected as the number of stops spanning the word boundary increases as in a three-stop sequence C#CC where underlined SF C1 stop is followed by a SI cluster. Furthermore, it is also anticipated that the HP of the underlined SI C1 in the two-stop sequence C#C will vary when preceded by a SI cluster as in the three-stop sequence CC#C. The effect of an increase in the number of stops on the HP of the underlined SF and SI stops in the CC#C and C#CC sequences when both occur as underlined in the four-stop CC#CC sequence will also be examined. The duration of SF and SI stop consonant clusters adjacent to the word boundary will also be measured to observe whether the duration of the cluster as a whole was affected as the number of stops following or preceding these clusters increases. For example, will there be a difference in the total HP of the underlined SF cluster in <u>CC</u>#C when this is followed by a singleton as opposed to when it is followed by a SI cluster as in <u>CC</u>#CC?

2- Do gestural coordination patterns across the word boundary vary as the number of stops in a sequence increases, and are the ICI distribution patterns stable for different sequence types?

This was motivated by the discussion in sections 2.4 and 2.5. As previously mentioned, coordination relationships between gestures govern the timing of gestures such that one gesture may begin at a point where another gesture has reached its target or is being released. The temporal relations of overlap between gestures of different segments are achieved through these coordination relationships. In order to understand how gestures are coordinated across a word boundary, the effect of an increase in the number of stops in a sequence on gestural coordination must first be investigated. Following the study by Zsiga (2000), the percentage of unmasked releases between any two adjacent stops in the C#C, CC#C, C#CC, and CC#CC sequences was first identified. The presence of an acoustic release in this position indicates the lack of stop closure overlap and open transition between gestures of adjacent stops whereas the absence indicates tighter gestural coordination. Secondly, in the discussion in section 2.4., it was noted that the lag interval between C1 release and onset of closure of C2 in a consonant sequence results in the occurrence of an ICI. A long ICI indicates a lesser degree of gestural coordination. The degree of gestural coordination was measured in terms of the temporal lag between release of C1 and CC2 closure. Studies by Cho (1998) and Zsiga (2000) have found that gestural coordination across word boundaries is weaker than within syllable boundaries. The mean durations of ICIs occurring in SI, SF, and across word boundaries are compared to determine whether the change in sequence type as a result of the number of stops involved and location of word boundary will have an effect on coordination relationships between gestures. For example in the CC#C sequence, is there closer gestural coordination exhibited between stops of the SF cluster or those spanning the word boundary. This will also identify the different epenthesis patterns occurring in the four sequence types under investigation.

3- Is the gestural coordination pattern across the word boundary affected by whether a coronal precedes a dorsal or a dorsal precedes a coronal?

In section 2.4.2, the effect of place order of consonants in a sequence, the anterior-posterior location of C1 constriction in relation to C2 constriction, was found to influence the articulatory coordination patterns between gestures. Studies have shown that the degree of gestural coordination differs between front-to-back and back-to-front place order (Hardcastle & Roach 1979, Byrd & Tan 1996, Zsiga 2000, 2003, Kochetov 2007). Some languages such as English have exhibited closer gestural coordination in the front-to-back place order (Hardcastle & Roach 1979). However, in other languages such as Russian, there was closer gestural coordination and less gestural lag between consonants across word boundaries in front-to-back sequences than in back-to-front sequences (Zsiga 2003). However, since all the stops investigated in this study involve lingual-palatal contact, the place order was referred to as coronal-dorsal, henceforth (CD) and dorsal-coronal, henceforth (DC).

4- Is the epenthetic vs. excrescent vowel distinction valid in TLA?

In section 2.5, different types of ICIs were discussed. In cases where gestural coordination is weak, the intrusion of the ICI between gestures is generally referred to as epenthesis. However, recent studies have shown that in some cases the ICI occurring between these consonant sequences is not actually an epenthetic vowel but is the by-product of the lack of overlap between the gestures of these consonants due to articulatory constraints (Browman & Goldstein 1990; Gafos 2002). These types of ICIs have been referred to as excrescent vowels (Gafos 2002; Gick & Wilson 2006). The answer to this research question will identify the different types of ICIs occurring in the four sequence types in TLA and their distribution patterns according to the epenthetic/excrescent vowel distinction.

5- Does voice assimilation occur across the word boundary in TLA and do different types of ICIs block voice assimilation?

This research question was motivated by the discussion in section 2.3.2.1. In this section, different languages were found to exhibit different voice assimilation patterns. When two adjacent segments disagreeing in voicing occur in a sequence, a regressive or progressive voice assimilation process may be triggered. This process may be total or partial. However, most voice assimilation studies focusing on Arabic dialects have shown that regressive voice assimilation is more common (Jordanian Arabic, Zuraiq & Abu-Joudeh 2013; Syrian Arabic, Teifour 1997, Heselwood & Ranjous 2008). In this study, voice assimilation was investigated in terms of the direction in which it occurs and the extent to which it occurs. It would also be interesting to find out whether the different types of ICIs block the assimilation process or not. It can be anticipated that, being short in duration, excrescent vowels may not block voice assimilation but longer true epenthetic vowels may.

6- Does an increase in speech rate have an effect on gestural coordination across word boundaries?

In section 2.4.2.3, speech rate was found to be one of the main factors affecting the degree of gestural coordination. As a result of changes in speech rate, gestures can be phased differently with respect to one another (Davidson 2003:174). Several studies have shown that an increase in speech rate results in closer gestural coordination and therefore longer gestural overlap periods and shorter ICIs. Being an important factor, the effect of speech rate was applied when investigating all the above research questions.

3.3 Participants

The subjects participating in this study are Libyan nationals and are all native speakers of TLA. In order to be selected for this study, the participants had to meet a number of criteria and requirements. The main criterion is that in order to be considered a native of Tripoli and thus a speaker of TLA, the subjects had to have been born and educated in Tripoli or its suburbs, and to have lived there most of their lives. Furthermore, all participants had no history of speech defects or hearing difficulties.

The participants were mainly recruited through personal contacts. All the participants took part in this study were students at the University of Leeds enrolled on a range of undergraduate and post-graduate courses. Unfortunately, no females were available during the data collection period, meaning that only male participants were approached and recruited. The number of participants that took part in this study was ten participants including myself as a native speaker of TLA. Of these ten participants, two were used for the EPG study. The age of the participants ranged between 20-41 years of age. Before agreeing to take part in the study, all participants were provided with an information sheet and consent form summarizing the aim of the study and a consent form informing them of their rights and obligations (see Appendix). Throughout this study, participants were anonymised for the sake of confidentiality and identified only by numbers. Ethical approval for the study was obtained from the Chair of the Arts and PVAC Faculty Research Ethics Committee at the University of Leeds (see appendix).

3.4 The data

In an attempt to answer the main research questions stated in section 4.2, and in order to investigate the effect of word boundaries on intergestural timing of stop consonants, the data consists of different types of stop consonant sequences across word boundaries in TLA. Given the syllabic template of TLA being $C^{1}_{2}VC^{0}_{2,}$ allowing a maximum of two consonants in both onset and coda position, this study focuses in particular on environments where more than two consonants occur across the word boundary where it can be predicted that a decrease in the degree of coordination at the word boundary occurs between the gestures of the stop consonants involved thus resulting in the occurrence of ICIs.

The data consists of two words separated by a word boundary. The first word ends in a lingual-palatal stop singleton or cluster and the second word starts with a lingual-palatal stop singleton or cluster. Beginning with the two-stop sequence of C#C which is the smallest possible stop sequence across the word boundary, the number of stops in the sequence gradually increases to include the three-stop sequences CC#C and C#CC, and finally ending with the largest possible four-stop sequence in TLA of CC#CC. This allows the investigation of the effect that an increase in the number of stops in a sequence has on gestural timing across a word boundary and therefore provides answers to research question 1.

The timing investigation is limited to the comparison between the same stop in different sequences. For example, in SF position, in C#C, the duration of C1 of the sequence will be compared to the duration of the same SF stop in C#CC. Similarly, in SF position, in CC#C, the duration of SF C2 will be compared with the same stop in CC#CC. Equally important, the SF stops in both the C#C and C#CC sequences are considered phonologically as being geminates in terms of their duration. This is due to the fact that they are preceded by a short vowel throughout the data. This is attested in Swedish and Arabic where geminates are always preceded by a short vowel (Majeed 2002). However, throughout the study these SF single stops will not be considered as geminates for two main reasons. The first is based on the classification presented by Heselwood & Watson (2013:51) that considers SF single stops as ‘pseudo geminates’ since they can contrast phonologically with true singletons. The other reason is that since this study adopts a gestural approach in investigating timing and coordination of stops in different sequences, these SF stops are considered single stops, not in terms of their durations but in terms of the gestures involved in their production, i.e. they are composed of single articulatory gestures. Therefore, throughout this thesis they are referred to as single articulatory gesture stops.

In addition, this study only focuses on lingual-palatal stops of the alveolar and velar regions in TLA /t,d,k,g/ occurring across the word boundary. The reason for this is twofold: to limit the data to a manageable size and because one of the limitations of the EPG is that it does not register labial articulations. This allows the control of the place order of stops across the word boundary, resulting only in coronal-to-dorsal and dorsal-to-coronal place order tokens. This classification of the data will facilitate providing an answer to research question 3 which investigates the effect of place order on gestural coordination across the word boundary. In addition, since the stops adjacent to the word boundary consist of a voiced and a voiceless alveolar stop /t,d/, and a voiced and a voiceless velar stop /k,g/, this allows all possible voicing combinations across the word boundary to be achieved in an attempt to answer research question 5 which investigates voicing assimilation across the word boundary.

In order to answer research question 2 regarding gestural coordination and ICI distribution patterns, ICIs occurring in SF, SI, and across word boundary in each sequence type were measured in order to find out if there is stability in the distribution pattern of ICIs for each sequence type and whether the ICI occurring at the word boundary is similar to the ICI occurring in the coda and onset clusters. Furthermore, the durations and properties of ICIs were identified in order to determine if the epenthetic/excrescent vowel distinction is valid in TLA in an attempt to address research question 4. Finally, research question 6 dealing with the effect of speech rate on gestural coordination was addressed by recording the data in both normal and fast speech rates making it possible to investigate whether an increase in speech rate results in closer gestural coordination across the word boundary.

Table 3.1, table 3.2, table 3.3, and table 3.4 present the data for each sequence type that was recorded:

Token	Gloss	Phonetic context
ʒit#tal	*bring a wire*	Vt#tV
ʒit#dis	*bring and hide*	Vt#dV
ʒit#kalb	*bring a dog*	Vt#kV
ʒit#giʃ	*bring hay*	Vt#gV
ʃid#tal	*hold a wire*	Vd#tV
ʃid#dis	*hold and hide*	Vd#dV
ʃid#kif	*catch a slap*	Vd#kV
ʃid#giʃ	*catch hay*	Vd#gV
fak#tal	*undo a wire*	Vk#tV
fak#dam	*undo blood*	Vk#dV
fak#kif	*undo a slap*	Vk#kV
fak#giʃ	*undo hay*	Vk#gV
dag#tal	*hammer a wire*	Vg#tV
dag#dam	*drink blood*	Vg#dV
dag#kif	*knock a slap*	Vg#kV
dag#giʃ	*hammer hay*	Vg#gV

Table 3.1 Target phrases in the two-stop sequence C#C and the target phonetic context

Token	Gloss	Phonetic context
wagt#tal	*wire time*	VCt#tv
wagt#daf	*pushing time*	VCt#dV
wagt#kif	*slap time*	VCt#kv
wagt#giʃ	*hay time*	VCt#gV
ʕagd#tal	*wire tying*	VCd#tV
ʕagd#dam	*blood tying*	VCd#dV
ʕagd#kam	*how much tying*	VCd#kV
ʕagd#gas	*cutting knot*	VCd#gV
hatk#tal	*wire beating*	VCk#tV
hatk#dam	*severe beating*	VCk#dV
hatk#kif	*smack beating*	VCk#kV
hatk#giʃ	*hay beating*	VCk#gV
fatg#tal	*wire hernia*	VCg#tV
fatg#dam	*blood hernia*	VCg#dV
fatg#kam	*how much hernia*	VCg#kV
fatg#gal	*hernia improved*	VCg#gV

Table 3.2 Target phrases in the three-stop sequence CC#C and the target phonetic context

Token	Gloss	Phonetic
bat#tkasir	broke overnight	Vt#tCV
nat#dkar	male anger	Vt#dCV
nat#kdab	became outraged and lied	Vt#kCv
nat#gtal	became outraged and killed	Vt#gCV
ʃad#tkasir	grasped (something) and broke	Vd#tCV
ʃad#dkar	male grasp	Vd#dCV
ʃad#ktir	grasping increased	Vd#kCV
ʃad#gtal	grasping killed	Vd#gCV
fak#tkasir	jaw broke	Vk#tCV
fak#dkar	male jaw	Vk#dCV
fak#ktir	mugging increased	Vk#kCV
fak#gtal	untied and killed	Vk#gCV
ʃag#tkasir	crack broke	Vg#tCV
hag#dkar	male right	Vg#dCV
nag#ktir	nagging increased	Vg#kCV
hag#gdi:m	old right	Vg#gCV

Table 3.3 Target phrases in the three-stop sequence C#CC and the target phonetic context

Token	Gloss	Phonetic context
wagt#tkasir	the time it broke	VCt#tCV
wagt#dkar	male time	VCt#dCV
wagt#ktab	book time	VCt#kCV
wagt#gdi:m	old times	VCt#gCV
ʕagd#tkasir	knot broke	VCd#tCV
ʕagd#dkar	male knot	VCd#dCV
ʕagd#ktab	book knot	VCd#kCV
ʕagd#gdi:m	old knot	VCd#gCV
hatk#tkasir	heavy beating	VCk#tCV
hatk#dkar	severe beating	VCk#dCV
hatk#ktir	beating increased	VCk#kCV
hatk#gdim	old beating	VCk#gCV
fatg#tkasir	hernia broke	VCg#tCV
fatg#dkar	male hernia	VCg#dCV
fatg#ktir	hernia increased	VCg#kCV
fatg#gdi:m	old hernia	VCg#gCV

Table 3.4 Target phrases in the four-stop sequence CC#CC and the target phonetic context

As can be seen from the tables above, all the words occurring on adjacent sides of the word boundary are monosyllabic words except for the token /tkasir/ which is polysyllabic. The reason for this is due to the lack of any monosyllabic word in TLA consisting of a SI cluster where C1 of the cluster is /t/. Therefore, in order to account for all types of combinations across the word boundary, a polysyllabic word was used. In addition, almost all the tokens include only the short vowels /i,a,u/ except for the token /gdi:m/ which consists of a long vowel /i:/. The reason for this is in an attempt to be consistent in terms of duration of the syllables on both sides of the word boundary.

Although all the individual words are widely used in TLA, in some cases they do not occur together. A few semantically anomalous phrases were used in order to account for all possible CD and DC place order of articulation across the word boundary in addition to accounting for all possible voice combinations.

3.4.1 Data collection

The recordings for the acoustic data took place in the recording studio of the Linguistics and Phonetics department at the University of Leeds, whilst the EPG data was recorded in the Language Research Laboratory. The word lists were recorded for both types of analyses. All the tokens under investigation were embedded in the same carrier phrase "*ma tguli:ʃ* -------------*." "*Do not say -------*." "* resulting for example in a sentence such as "*ma tguli:ʃ wagt ktab" "*do not say it is book time*"*. The sentence was produced without any pauses with the phrasal boundary being at the end of the last word in the phrase. The sentences containing the target phrases were typed in Arabic orthography on normal A4 paper with each phrase on a separate line and each sequence type on a separate sheet resulting in a total of 4 separate sheets. In order to investigate the effect of speech rate on the temporal and spatial organization of the gestures of the consonants under investigation, speakers produced the tokens at two speech rates, normal and fast. For each of these speech rates, each token was repeated 4 times by each speaker and the first three repetitions were used for the analysis. The last repetition was eliminated due to the fact that speakers tend to lengthen this token during recordings. Prior to any recording session, the subjects, two in this case including myself, were given enough time to go over the sentences in order to familiarize themselves with their production and in order to produce the phrases fluently. During this period, the participants read through the tokens and were given sufficient time until they found themselves comfortable to begin the recording session.

Each recording session lasted between 40 and 50 minutes. This was divided into two sessions for each speech rate with a 10 minute break in between when the participants were provided with refreshments. The same procedure was followed for the EPG and the data was recorded in both normal and fast speech rates. However, due to the fact that the artificial palate becomes uncomfortable after a period of time, a break was given between the recordings of each sequence type. As a result, the recording session for the EPG data lasted longer ranging between 60-90 minutes.

3.5 Data analysis

Three methods of data analysis were used in the study. The first is the EPG analysis, the second is the acoustic data analysis, and finally statistical software analysis was also used to calculate significant differences between variables, mean durations of segments, mean percentages, and the plotting of graphs. All durational measurements were in milliseconds. The data were coded in order to facilitate statistical investigation. In the case of the release of stops, the presence of a release was assigned a ‘1’ value and the absence of a release for a specific stop was assigned a ‘2’ value. This was also used to indicate the presence or absence of an ICI. In the case of voicing during the production of stops and ICIs, this feature was coded into five different categories. ‘1’ = fully voiced, ‘2’ = partially voiced when a voiceless segment is slightly voiced, ‘3’ = devoiced when a voiced segment is totally devoiced, ‘4’ = voiceless, and finally ‘5’ partially devoiced when a voiced segment is slightly devoiced. Table 3.5 explains the coding system used in this study.

Feature	Category	Code
Stop release	Release	**1**
	No release	**2**
Voicing of stops and ICIs	Fully voiced	**1**
	Partially voiced	**2**
	Devoiced	**3**
	Voiceless	**4**
	Partially devoiced	**5**

Table 3.5 Coding system adopted in study

Following several previous studies investigating oral stop durations (Flege & Port 1981), (Kent & Read 1999), (Shaheen 1979), the duration of a stop was identified as the total duration between the onset of closure to the point of release, i.e. the HP. The main reason for this is to be consistent in duration measurements in both the EPG and acoustic data due to the fact that only stop closure durations are measured from the EPG frames. Another reason is that in this study also investigates the occurrence of ICIs between stops. Throughout this study, whether a stop is released or not is an important indicator of gestural coordination and timing. In addition, the length of time before the onset of closure of the following stop, i.e. the duration of the ICI is of equal importance. As previously mentioned, the degree of gestural coordination was measured in terms of the temporal lag between release of C1 and C2 closure. Primarily the duration of ICI in this study was measured immediately after the release burst of C1 to the onset of closure of C2. Furthermore, there are four oral stops under investigation in this study /t,d,k,g/ all situated adjacent to word boundaries. In some cases, C1 of a consonant sequence may not be released and therefore it was only possible to account for the hold phase of that particular stop in the EPG data. Therefore, for the purpose of consistency, the duration of the stop was identified as the hold phase in both the EPG and acoustic data analysis.

The point of release of stops can be easily identified on a spectrogram. This is characterized by the abrupt opening of the articulator resulting in a sudden increase in the acoustic energy which can be noticed as a vertical spike after a period of silence. However, deciding the start point of the closure by a spectrogram alone may be rather problematic. Under normal circumstances, the point where a periodic wave fades away in the waveform and higher frequency energy suddenly decreases in the spectrogram is assumed to be the starting point of the closure. For that reason, both the waveform and the spectrogram were used in identifying the hold phase of stops under investigation. The most important criterion is was consistency in all measurements across the whole data.

The total mean duration of SF and SI stops adjacent to the word boundary across all four contexts was calculated in order to compare the mean duration in each sequence type. Then the mean duration of the same stops was calculated across all four contexts for each speaker in order to compare the individual productions of speakers with the general pattern. The same process was be applied to SF and SI consonant clusters to find out if the total duration of the cluster is also affected by the number of stops on the adjacent side of the boundary.

The total mean duration of SF, word boundary, and SI ICIs occurring in different contexts was also calculated for comparison purposes. The mean ICI durations for the productions of each speaker was also calculated and compared with the general pattern in order to investigate if any variability between speakers occurred. This sheds light on gestural coordination between different stops.

Release and no release percentages across the word boundary in each sequence type were also calculated and compared in order to identify across word boundary gestural coordination. Following Zsiga (2000) and Wright (1996), an increase in the release percentage between two stops in a specific sequence indicates a decrease in gestural coordination. Furthermore, in the case of the EPG data where it was possible to measure overlap duration, the effect of CD and DC order of place of articulation on gestural overlapping across the word boundary was investigated. The data was divided according to the order of place order of the stops involved. The overlap duration was assigned a negative (-) value, and the ICI duration was assigned a positive (+) value for each place order. The mean values for both place orders were compared. A negative value indicates that the HP of the two gestures overlaps, whereas a positive value indicates a lag between the constrictions for the two gestures. The tokens where the stops adjacent to the word boundary shared the same place of articulation were excluded from this investigation since the place order is the same. On the other hand, in the acoustic data where it is not possible to measure overlap duration, this investigation was limited to gestural coordination and not overlapping across word boundaries. Here the lag duration and the resulting ICI reflect the degree of gestural coordination across the word boundary.

3.5.1 Electropalatography (EPG)

EPG has been used in speech research for over twenty five years for analyzing connected speech processes such as coarticulation and assimilation. EPG has also been used to study speech related disorders such as cleft-palate and hearing impairment. The EPG consists mainly of two components, the artificial palate and an electric device detecting and displaying patterns of contact between the tongue and the palate during the process of speech. The subject wears an acrylic palate with silver sensors attached to the surface and connected with lead wires to a computer. When the tongue comes into contact with one of the sensors, a circuit is completed and the signals travelling through the lead wires are registered by the computer.

There are different EPG systems used today for speech research. For this study, the Articulate EPG palate was used. Due to the relatively high price of the articulate palate, in addition to the time-consuming process of having one made, only two participants were recorded for the EPG data; myself and another native speaker of TLA. The first Reading EPG palate made for myself was unsuccessful since it did not account for velar closures; thus, another Articulate EPG palate was ordered and used for this study. Both participants in the EPG data investigation used the Articulate palate.

There are a total of sixty two sensors embedded on the surface of the artificial palate. These sensors are arranged in eight horizontal rows each row having eight sensors except for the anterior row which has only six sensors. The first row corresponds to a line immediately behind the upper front teeth and the last row corresponds to a line between the hard and soft palate. The sensors within each row are evenly spaced but the distances between the rows vary for different parts of the palate, see Figure 3.1.

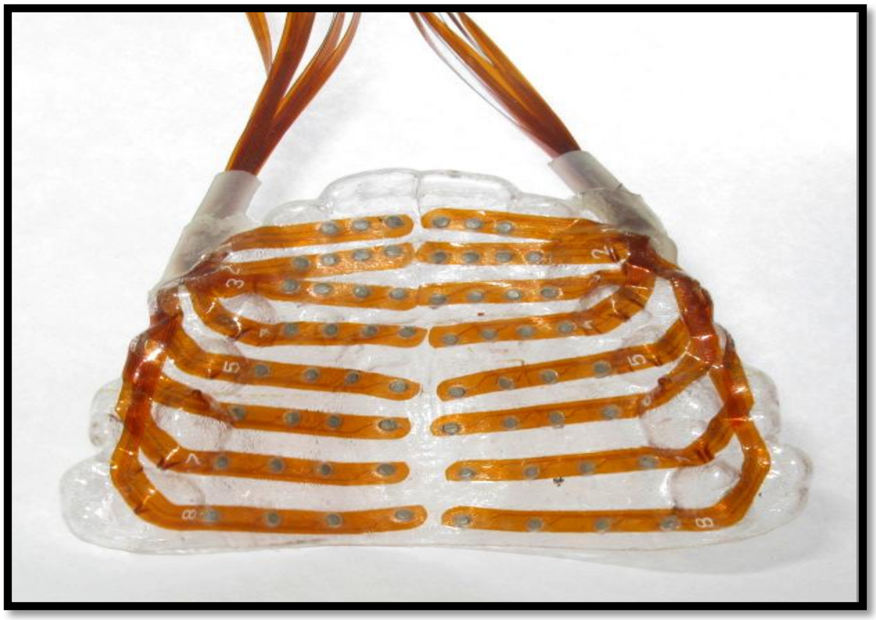


Figure 3.1 Articulate EPG palate used in this study

Authors have differed in the way that they divide up the artificial palate into different zones. Hardcastle (1989) divides the artificial palate into three zones: alveolar rows 1-3, palatal rows 4-5, and velar rows 6-8. On the other hand, Recasens *et al.* (1993) preferred a division consisting of two major zones: the alveolar zone from rows 1 to 4 and the palatal zone from rows 5 to 8. They then further divided the alveolar zone into two subzones: the front alveolar (rows 1 to 2) and the post-alveolar (rows 3 to 4). The palatal zone was also subdivided to create a pre-palatal zone (rows 5 to 6), a medio-palatal zone (rows 6 to 7), and a post-palatal zone (row 8).

In this study, the artificial palate was divided into three zones following Hardcastle (1989). Rows 1-3 correspond to the alveolar region and rows 6-8 the velar region (figure 3.2). This division was due to the fact that no palatal sounds were investigated with alveolar and velar stops constituting the main area of investigation.

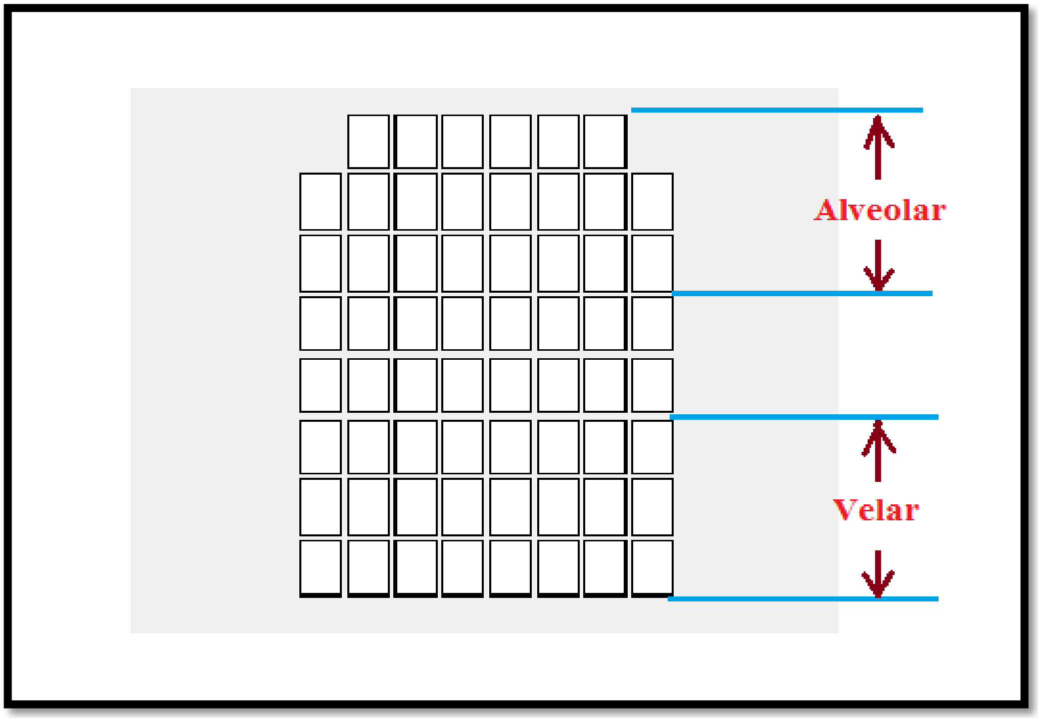


Figure 3.2 EPG palate showing rows corresponding to alveolar and velar contact regions

EPG has many advantages over the other devices which have previously been used in articulatory studies. EPG allows the monitoring of changes in tongue-palate contact patterns of a speech segment over time at intervals of ten milliseconds. This method enables us to trace the developing pattern of contact between the tongue and the roof of the mouth: where, when, and how major constrictions start and end. It also enables the identification of the presence or absence of open oral tract during the production of stop consonant sequences signaling the presence or absence of vocalic elements during their production. As EPG allows continuous speech to be recorded, it offers a significant advantage for the study of connected speech. The most important advantage that the EPG has over acoustic analysis is its ability to measure the overlap duration between two adjacent segments. This proves useful not only in investigating the degree of gestural coordination but also the amount of overlap between stops under investigation. Furthermore, the EPG display also provides acoustic data analysis accompanying the EPG data display which is also used to facilitate durational measurements of segments. Furthermore, the acoustic analysis accompanying the EPG was also used to infer articulatory behaviour from the other acoustic data.

However, this device also has some limitations, one of these being the fact that it only records contact on the hard palate and as a result, the area of the palate where contact for /k/ occurs is sometimes incompletely recorded (Pouplier *et al.* 2010:624). Borden et al. (2003:224) also point out the fact that the artificial EPG palate lacks sensors at the most anterior part of the alveolar ridge, the teeth, in addition to the velum and therefore no there is no record of any articulatory contact for these regions. They also state that the uneven distribution of the sensors on the surface of the palate may provide a large amount of data where there is sensor concentration but less detail where there is lack of concentration of the sensors. In addition, the EPG cannot record bilabial closures since it does not cover the lips. However, this does not affect this study since only lingual-palatal stops were investigated. Nevertheless, even with these limitations, the EPG was very useful for investigating the articulatory aspects of speech sounds in this study.

The EPG was used to measure durations of singleton stops and stop clusters adjacent to the word boundary. ICI durations within coda, onset, and word boundary positions were also measured. In addition, the occurrence or absence of stop releases across the word boundary and the overlap period between two stops adjacent to the word boundary was also measured from the EPG data.

The duration of a stop HP was identified as the interval between the first EPG frame showing complete closure in the oral tract to the last EPG frame showing the same closure as seen in Figure 3.3. In this token, /dag#dam/, the duration of /g/ was measured starting from frame 184, which is the first frame showing a complete velar closure, to frame 198 which is the last frame with the same velar closure. Given that the duration of each EPG frame is 10ms, the total duration of singleton coda /g/ in this example was 15x10=150ms.

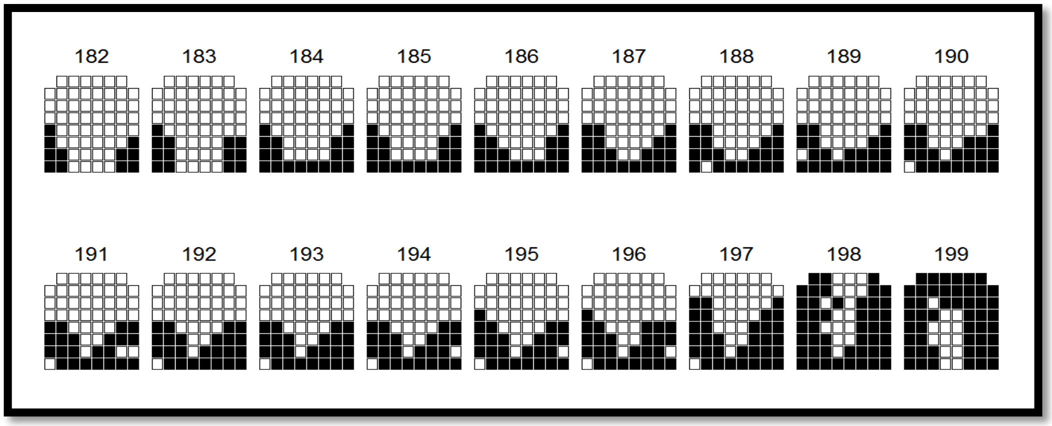


Figure 3.3 EPG frames 184-198 corresponding to duration of velar /g/ in the token /dag#dam/ normal speech rate

In the case of ICI measurements, the ICI duration between two stop consonants C1C2 was identified as the interval between the first EPG frame showing an open oral tract following C1 closure to the last frame showing an open oral tract preceding the C2 closure. In the token /ʕagd#gdi:m/ Figure 3.4, a word boundary ICI can be seen between the alveolar and velar closures. This ICI begins from EPG frame 80 which is the first frame following the alveolar closure to frame 83 which is the last frame showing an open oral tract preceding the velar closure in frame 84. The duration of the ICI period in this example was measured as 4x10=40ms.

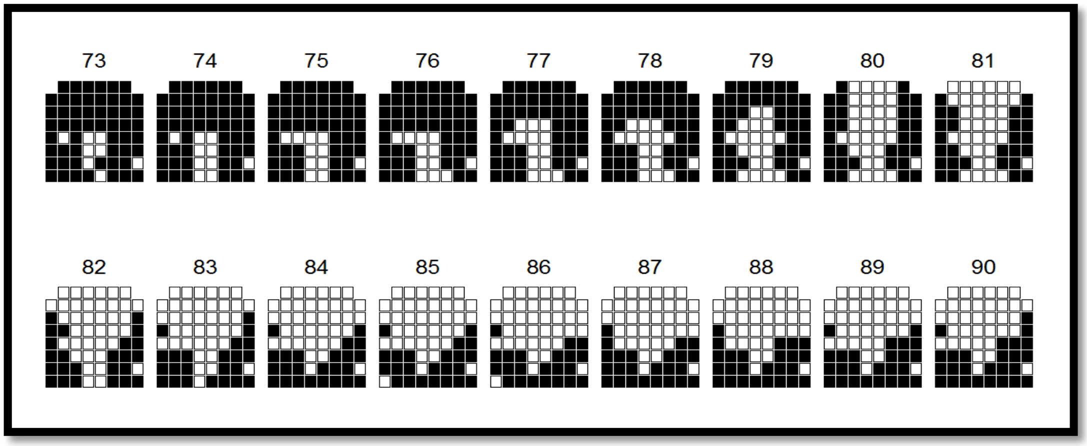


Figure 3.4 EPG frames 80-83 corresponding to #ICI duration the token /ʕagd#gdi:m/ normal speech rate

As for the duration of stop clusters C1C2 in SF and SI positions, these were identified as the interval between the first frame showing complete closure for C1 to the last frame showing closure for C2 prior to the release. This is further highlighted in the SF cluster /gt/ in the token /wagt#tal/ Figure 3.5 where C1 is not released until after the formation of the C2 closure and therefore there is no ICI.

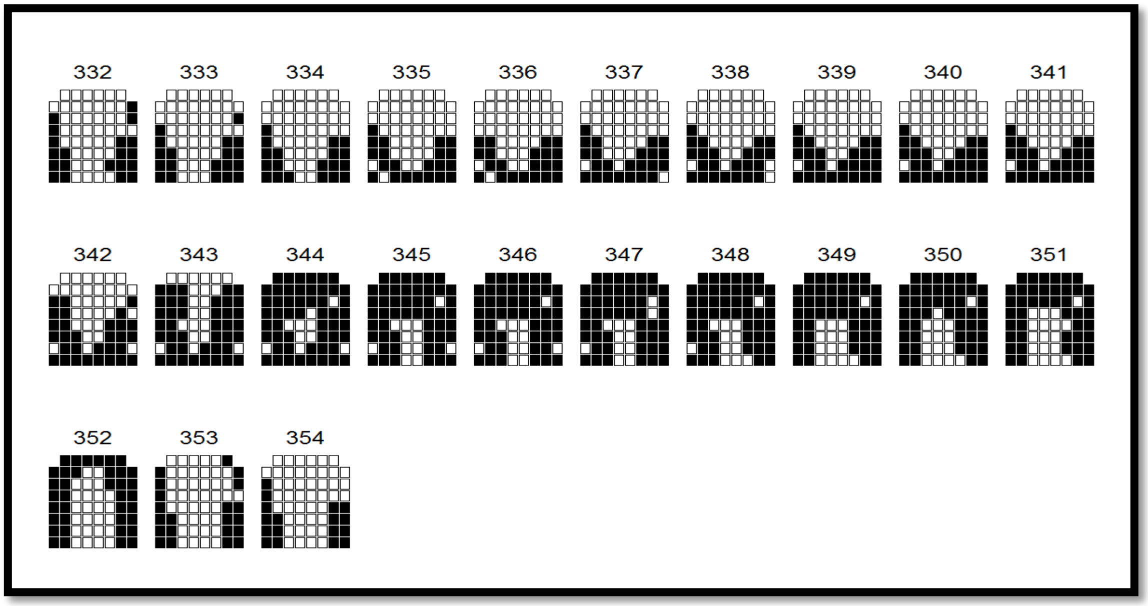


Figure 3.5 EPG frames 335-352 corresponding to duration of coda cluster /gt/ in the token /wagt#tal/ normal speech rate

The syllable-final cluster /gt/ in this example was measured as the interval between frame 335 showing the onset of velar closure of C1 to frame 352 being the last frame of the C2 alveolar closure. The syllable-final cluster /gt/ in this example was measured as 180ms. In cases where a release between the hold phases of two stops occurs resulting in an ICI, being a by-product of the cluster production, the ICI duration was included in the total duration of the cluster.

As for the case of measurements taken for overlap duration where the release of a stop is masked by the formation of a following stop, the duration of overlap was identified as the interval between the first frame where a second closure is formed while retaining a previous closure to the last frame where the second closure is released, i.e. the overlap of the hold phase of two gestures. These overlap durations can be seen in figure 3.5 and 3.6. In the token /fak#tal/ figure 3.6, the release of velar /k/ closure is masked by the formation of the alveolar /t/ closure resulting in a period of gestural overlap. The overlap period was measured as the interval between frame 294 exhibiting the occurrence of both an alveolar and velar closure and frame 297 which is the last frame exhibiting the double closure prior to the release. The overlap interval in this example was measured as 4x10=40ms.

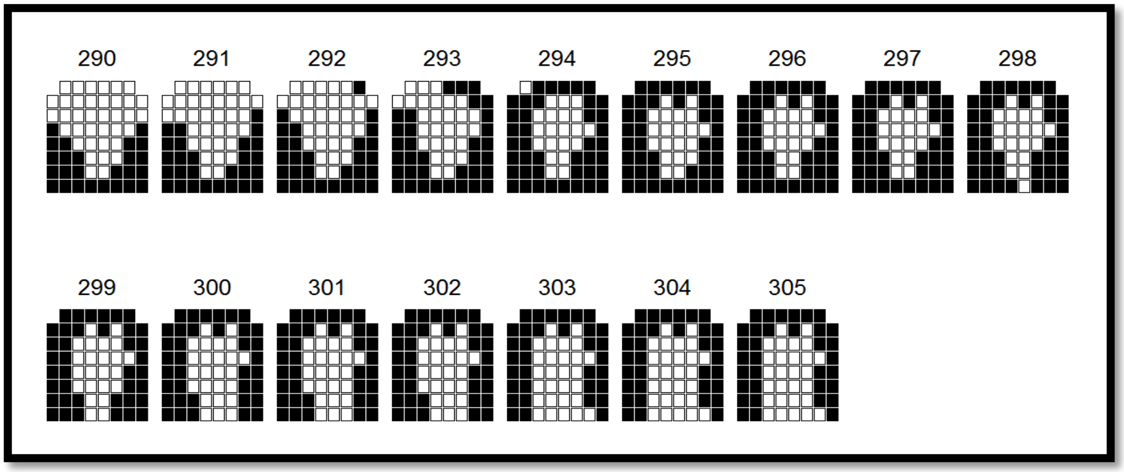


Figure 3.6 EPG frames 294-297 corresponding to duration of word boundary overlap in the token /fak#tal/ normal speech rate

For each investigation, the EPG data was first analyzed in terms of the total productions of both speakers in order to find out the general pattern. Later, and in order to find out if any variability existed between speakers, the data for each speaker was analyzed separately.

3.5.2 Acoustic software analysis

Articulatory activity is not directly represented in acoustic displays but can be inferred from them if the likely articulatory correlates of acoustic features and patterns are known. For example, in investigating the effect of the order of place of articulation on gestural coordination, overlap durations were inferred in the acoustic data on the basis of the EPG data. For this reason, the EPG analysis was conducted before the acoustic data analysis. This is due to the fact that the EPG has several advantages as mentioned in section 4.5.1. The acoustic data accompanying the EPG was used to infer articulatory behaviour from the other acoustic data. The software used in this study for acoustic analysis is PRAAT. It is a computer software through which speech can be analyzed, synthesized, and manipulated. PRAAT displays speech using a digital spectrogram and time domain waveform. Since most of the acoustic analysis in this study is based on durations, both these displays are almost equally useful depending on different contexts. According to Ladefoged (2003:138) the best method used in measuring most aspects of duration is in terms of points on the waveform. He also adds that in some cases, spectrograms can also provide useful data in support of these measurements. For example, formants and formant transitions are best analyzed using spectrograms. On the other hand, stop closure onset, closure release, voicing offset during the stop closure, voicing onset for the vowel are better measured using the waveform.

For this study, measurements were taken from the waveform with reference to the spectrogram. The reason being that in some contexts it is sometimes difficult to rely on only one of these. For example, acoustic releases are better identified using the waveform since the sudden release of the articulators results in a vertical spike on the waveform after a period of silence. In cases of voiced stops, where there is continuous vibration in the waveform, it is sometimes easier to identify the acoustic release using the spectrogram because the sudden release of the articulators can be identified as a sudden increase in high frequency acoustic energy following a period of absence of acoustic energy. Furthermore, the onset of the HP was identified using both the waveform and spectrogram, where it was identified as the point of abrupt amplitude drop (Watt 2013:94). In some cases especially in voiceless stops due to the lack of vocal fold vibration in the waveform, the spectrogram was also used to determine the onset of the HP which was identified by the decrease in higher frequency energy.

The HP of a stop was measured as the distance between the onset of the closure and the onset of the release. This can be highlighted in the duration of /t/ in the token /nat#gtal/ of Figure 3.7.

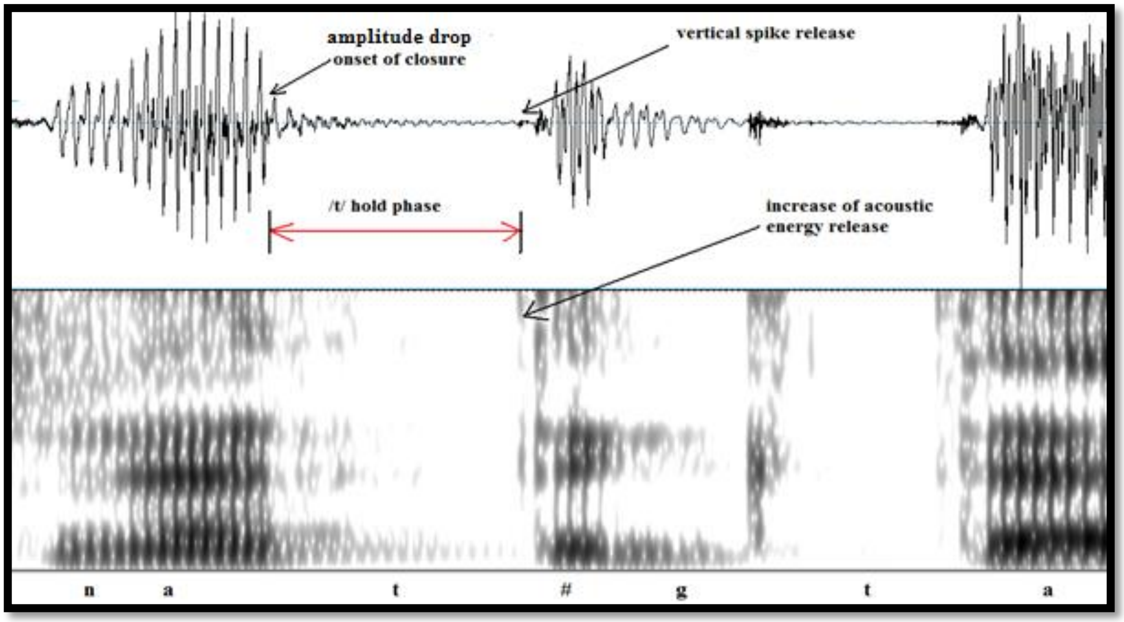


Figure 3.7 Screenshot from PRAAT showing hold phase of /t/ in /nat#gtal/ in waveform and spectrogram

It is sometimes the case where a stop release is masked by the closure of a following stop resulting in the overlapping of gestures between C1 and C2. In these cases the duration of C1 was considered to be half of the total duration of the cluster.

In the case of consonant clusters C1C2, the total duration was measured from the onset of closure of C1 to the acoustic release of C2. In cases where an acoustic release of C1 of the cluster occurs resulting in an ICI duration, being a by-product of the cluster production, the ICI duration was included in the total duration of the cluster.

One of the disadvantages of any acoustic speech analysis software is the inability to measure overlap durations in cases where the hold phase of two adjacent stops overlap. Unlike the EPG analysis, the onset of closure of the second stops is impossible to identify from the spectrogram or waveform. Therefore, in the acoustic data analysis section of this study, it was not possible to account for gestural overlap. The degree of gestural coordination was measured in terms of the temporal lag between release of C1 and C2 closure. This was identified by the duration of the ICI occurring between adjacent stops. The longer the ICI, as confirmed by the EPG analysis, the more the gestures are pulled apart resulting in less gestural coordination. A short ICI indicates closer gestural coordination between two adjacent stops.

3.5.3 Statistical analysis

The statistical software used in this study was the IBM SPSS 20 statistical package. SPSS was used in this study to calculate the mean duration of stops and ICIs in addition to the release percentages across word boundaries for all contexts. It was also used for producing visual data in the form of tables, bar charts, and graphs in presenting results for the mean durations of stops and ICIs in different contexts.

In order to test the significance of the results obtained, statistical significance tests were also carried out to identify any significant differences between variables. A significance threshold of 0.05 was used. Any significance results where p value is <0.05 was considered to be significant between groups of variables whereas a significance result of >0.05 was not considered to be significant. Before conducting any significance tests, in cases where the variables are continuous, such as in ICI and stop durations, a normality test was carried out in order to determine whether the data is normally distributed or not or whether it contains outliers. Normality tests were carried out by conducting a Shapiro-Wilk test for normality. Any significant value of <0.05 in this test indicates that the data distribution for a specific variable being not normally distributed (Laerd statistics 2014). In such cases, nonparametric tests were conducted since these are not affected if the data is not normally distributed and outliers are present (Laerd statistics 2014).

In those cases where only two independent groups of variables are to be tested for significant differences between their means and the data distribution for both variables is normally distributed, an independent sample T-test was conducted to test for any significant differences. This type of test is used to establish if there is any significant difference between the means of two independent samples (Norris et al 2012).

If more than two groups of variables are to be tested for significant differences and the data distribution for the variables being tested is normally distributed, a One-way ANOVA should first be conducted to compare whether the groups are statistically significantly different. The One-way ANOVA is used to find out if the means for each group are significantly different from each other by using variances (Norris et al 2012). However, the One-way ANOVA only compares within group variation and cannot determine significant differences between specific groups. Therefore, if the One-way ANOVA results in a significant difference of <0.05, a Bonferroni Post Hoc test which compares across group variations should be conducted to examine which specific group of variables is significantly different from others.

However, when the data was not normally distributed, non parametric tests were carried out to test for significant differences. In such cases, when comparing between two variables, a Mann-Whitney U nonparametric test was used to test for significance due to the fact that this test is not affected by the presence of outliers since the calculations are based on medians and not on means and is therefore used when the data is not normally distributed (George & Mallery 2012).

In those cases when more than two variables were being tested for significant differences but the data was not normally distributed due to the presence of outliers in the variables, a Kruskal-Wallis non-parametric test was applied to test for significant differences between the variables due to the fact that this test is not affected by the presence of outliers in the data.

Throughout the data analysis in this study, unless stated otherwise, the data were considered to be normally distributed based on the results of the normality tests and parametric tests which were carried out. However, any non-normal distribution of data was highlighted before conducting non-parametric tests.

Chapter 4 EPG results

4.1 Introduction

This chapter consists of two main sections, the first focusing on articulatory timing of stops and the second on gestural coordination. In answer to the first research question, section 4.2 presents the results of the effect that an increase in the number of stops in a sequence has on the timing of SF and SI stops. The HP of SF and SI stops adjacent to the word boundary as highlighted by the EPG frames are compared in the C#C, CC#C, C#CC, and CC#CC sequences. Similarly, the timing of clusters including any intervening ICI in both SF and SI positions is presented to determine if the articulatory behaviour of clusters as a whole is also affected by the increase. Section 4.3 presents the results of the intergestural timing and patterns of gestural coordination in stop sequences in an attempt to address the second research question. This includes the percentage of stop releases occurring across the word boundary in the four sequence types in addition to ICI duration and distribution patterns. Finally, section 4.4 presents the results of the effect of place order of stops involved on gestural coordination in order to address the third research question.

4.2 The influence of the number of stops in a sequence on the timing of SF and SI stops and clusters

In this section, the timing of stops and stop clusters adjacent to the word boundary, whether in SF or SI position, are presented and compared. The results shed light on the effect an increase in the number of stops in the sequence has on the duration of SF and SI stops adjacent to the word boundary in the four sequence types and therefore aims to answer research question 1.

4.2.1 The influence of the number of stops in a sequence on the timing of SF stops

The results of the timing of SF stops /t,d,k,g/ in four positions are presented, two occurring as SF single articulatory gesture stops in tokens of the **C**#C and **C**#CC sequences, and two occurring as C2 of the SF cluster in tokens of the C**C**#C and C**C**#CC sequences. The results shed light on the effect an increase in the number of stops in the sequence has on the duration of SF stops adjacent to the word boundary in the four sequence types and therefore aims to answer research question 1.

4.2.1.1 SF alveolar /t/ and /d/

The EPG results reveal that the mean HP duration of SF singleton stops /t/ and /d/ was longest when occurring in the **t**#C and **d**#C sequence tokens respectively. The mean HP of the singleton /t/ gesture (table 4.1) was 123ms at normal speech rate and 107ms at fast speech rate whereas the voiced counterpart /d/ (table 4.2) averaged 132ms in normal speech rate and 99ms in fast speech rate in tokens of the **d**#C sequence when followed by a SI singleton stop. As the number of stops increased in SI position in tokens of the t#**CC** sequence, the mean HP of /t/ decreased to 104ms in normal and 76ms in fast speech rates. This decrease was also exhibited by /d/ in tokens of the **d**#CC sequence in normal and fast speech rates.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
t#C	ʒit#tal	111.67	6	10.328	89.17	6	19.343
	ʒit#dis	104.17	6	10.685	84.17	6	15.626
	ʒit#kalb	141.67	6	8.756	115.00	6	20.000
	ʒit#giʃ	135.00	6	18.708	140.00	6	43.359
Mean		**123.12**	**24**	**19.881**	**107.08**	**24**	**33.909**
t#CC	bat#tkasir	66.67	6	19.408	45.00	6	14.832
	nat#dkar	112.50	6	43.789	69.17	6	15.943
	nat#kdab	128.33	6	12.910	92.50	6	13.323
	nat#gtal	109.17	6	8.612	100.00	6	8.944
Mean		**104.17**	**24**	**33.090**	**76.67**	**24**	**25.353**

C**t**#C	wagt#tal	97.00	6	12.329	75.50	6	10.932
	wagt#daf	73.33	6	8.756	63.67	6	5.538
	wagt#kif	90.83	6	11.143	61.67	6	14.376
	wagt#giʃ	71.67	6	12.517	60.83	6	17.725
Mean		**83.21**	**24**	**15.354**	**65.42**	**24**	**13.503**
C**t**#CC	wagt#tkasir	61.17	6	14.972	55.33	6	11.690
	wagt#dkar	87.00	6	12.247	60.33	6	19.408
	wagt#ktab	82.00	6	31.305	66.17	6	19.343
	wagt#gdi:m	84.50	6	26.599	64.50	6	5.244
Mean		**78.67**	**24**	**23.621**	**61.58**	**24**	**14.738**

Table 4.1 Mean HP duration of SF /t/ normal and fast speech rate

This decrease in duration is also exhibited by both stops when occurring as C2 of the SF cluster as a result of the increase in the number of stops across the word boundary in SI position. When occurring as SF C2 of the SF cluster, the mean HP of the TT gesture in the C**t**#C sequence was 83ms in normal speech rate and 65ms in fast speech rate. This decreased to 78ms in normal speech rate and 61ms in fast speech rate in the C**t**#CC sequence. Figures 4.1 and 4.2 highlight the difference in the timing of the /t/ gesture in the C**t**#C and C**t**#CC sequences.

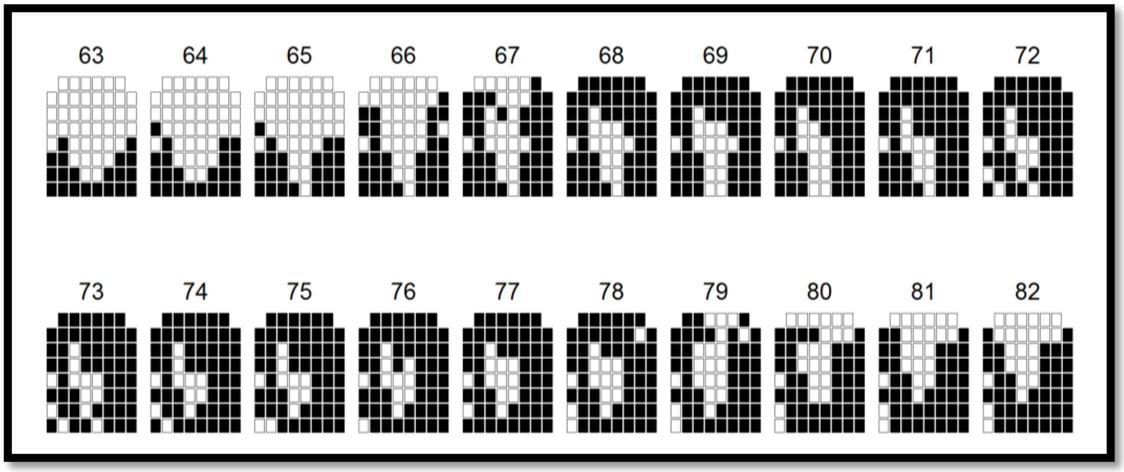


Figure 4.1 Long HP of SF /t/ in /wagt#kif/ by speaker 1 at normal speech rate. Frames 68 to 78 show an alveolar /t/ closure of about 110ms.

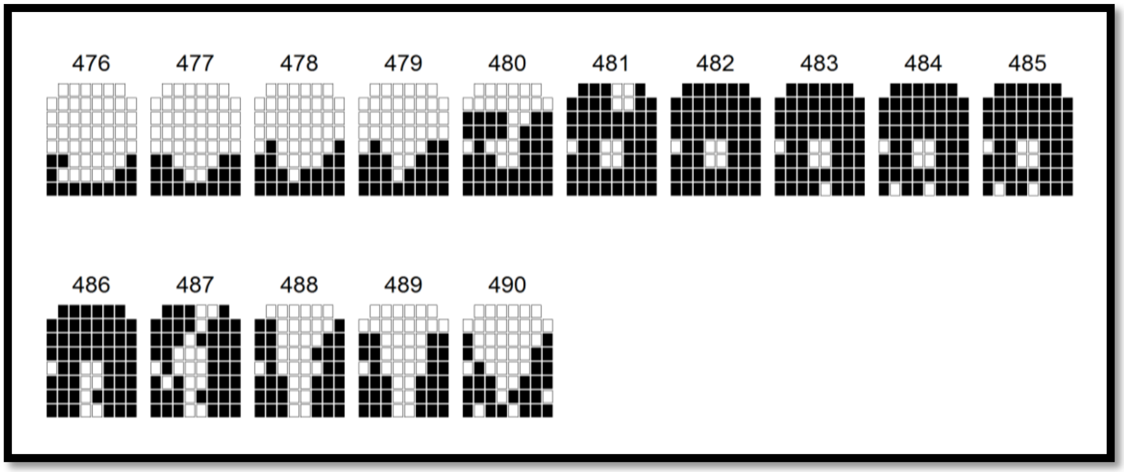


Figure 4.2 Short HP of SF /t/ in /wagt#ktab/ by speaker 1 normal speech rate. Frames 481 to 486 show an alveolar /t/ closure of about 60ms.

As for the voiced counterpart /d/, the mean HP averaged 83ms in normal and 70ms in fast speech rate in tokens of the C**d**#C sequence and 76ms in normal and 63ms in fast speech rate in tokens of the C**d**#CC sequence.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
d#C	ʃid#tal	126.67	6	16.021	94.17	6	15.303
	ʃid#dis	107.50	6	22.749	79.17	6	7.360
	ʃid#kif	145.83	6	41.643	119.17	6	11.583
	ʃid#giʃ	150.83	6	30.069	105.00	6	14.142
Mean		**132.71**	**24**	**32.369**	**99.38**	**24**	**18.957**
d#CC	ʃad#tkasir	94.17	6	17.151	74.17	6	9.174
	ʃad#dkar	98.33	6	15.706	76.33	6	9.730
	ʃad#ktir	113.33	6	13.663	94.17	6	15.943
	ʃad#gtal	108.33	6	35.024	100.00	6	17.607
Mean		**103.54**	**24**	**22.041**	**86.17**	**24**	**17.057**
C**d**#C	ʕagd#tal	88.17	6	10.028	71.67	6	7.528
	ʕagd#dam	73.67	6	3.830	68.33	6	8.959
	ʕagd#kam	84.17	6	17.151	77.50	6	16.355
	ʕagd#gas	84.33	6	26.357	61.67	6	19.408

Mean		**82.58**	**24**	**16.442**	**69.79**	**24**	**14.283**
C**d**#CC	ʕagd#tkasir	78.33	6	12.111	75.00	6	16.125
	ʕagd#dkar	73.33	6	18.886	49.17	6	20.104
	ʕagd#ktab	73.33	6	14.024	64.17	6	15.943
	ʕagd#gdiːm	79.17	6	4.916	63.33	6	6.831
Mean		**76.04**	**24**	**12.852**	**62.92**	**24**	**17.252**

Table 4.2 Mean HP duration of SF /d/ at normal and fast speech rates

These results indicate that whether /t/ or /d/ are a SF singletons or C2 of a SF cluster, the duration decreases as the number of consonants following the word boundary increases as highlighted in figures 4.1 and 4.2. Results also show that the HP is shorter in fast speech than in speech at a normal rate.

4.2.1.2 SF velar /k/ and /g/

The HP of the SF TB /k/ and /g/ gestures also exhibit a similar pattern in both normal and fast speech rates. The mean HP duration of the singleton TB gesture /k/ was longest in the k#C sequence where it averaged 129ms in normal and 99ms in fast speech rate. The mean HP decreased when followed by a SI cluster in tokens of the k#CC. This decrease in the mean HP duration of the TB /k/ gesture is also exhibited when TB /k/ occurs as C2 of the SF cluster in tokens of the Ck#C and Ck#CC sequences. Furthermore, the duration of the HP also decreased as a result of the increase in speech rate.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
k#C	fak#tal	150.83	6	11.143	113.33	6	14.720
	fak#dam	133.33	6	14.720	110.00	6	21.213
	fak#kif	113.33	6	7.528	86.67	6	8.165
	fak#giʃ	120.33	6	15.449	88.67	6	6.218
Mean		**129.46**	**24**	**18.734**	**99.67**	**24**	**17.890**
k#CC	fak#tkasir	110.83	6	22.895	90.83	6	21.545

	fak#dkar	120.83	6	34.988	99.17	6	23.327
	fak#ktir	98.33	6	22.730	89.17	6	11.583
	fak#gtal	100.00	6	11.402	88.33	6	15.055
Mean		**107.50**	**24**	**24.628**	**91.88**	**24**	**17.804**
C**k**#C	hatk#tal	88.83	6	13.197	70.00	6	5.477
	hatk#dam	95.83	6	23.112	68.33	6	6.831
	hatk#kif	95.00	6	14.142	71.67	6	4.082
	hatk#giʃ	76.17	6	10.685	65.00	6	3.162
Mean		**88.96**	**24**	**16.936**	**68.75**	**24**	**5.367**
C**k**#CC	hatk#tkasir	54.17	6	16.558	42.50	6	14.748
	hatk#dkar	54.17	6	25.577	62.50	6	12.145
	hatk#ktir	74.17	6	8.010	61.67	6	16.330
	hatk#gdi:m	79.17	6	11.583	82.50	6	19.170
Mean		**65.42**	**24**	**19.500**	**62.29**	**24**	**20.641**

Table 4.3 Mean HP duration of SF /k/ at normal and fast speech rates

The only exception is found in /hatk#giʃ/ of the Ck#C and counterpart /hatk#gdi:m/ of the Ck#CC tokens. In both normal and fast speech rates, the mean HP of SF C2 TB /k/ gesture was longer when followed by a SI cluster in /hatk#gdi:m/ in comparison to /hatk#giʃ/. This is not consistent with other tokens that exhibit a decrease in the mean HP duration as the number of stops increase in SI position.

Results of the mean HP duration of SF singleton TB /g/ gesture in normal speech rate also indicate that the durational pattern decreases as the number of stops increases in SI position of the sequence (table 4.4). As with other SF stops investigated, the mean HP duration of the SF /g/ was longest when occurring as a singleton in tokens of the g#C sequence averaging 119ms in normal speech rate and 91ms in fast speech rate. This decreased in normal and fast speech rates as the same singleton gesture is affected by the increase in the number of stops in SI position when occurring in tokens of the g#CC sequence. Despite this pattern, the mean HP of the SF single articulatory gesture stop /g/ in /hag#gdi:m/ of the g#CC sequence was longer than when occurring in /dag#giʃ/ of the g#C sequence when followed by only a SI singleton stop.

The decrease in the mean HP duration as result of the increase in the number of stops in SI position is also evident when comparing the mean HP of the SF C2 /g/ when occurring in tokens of the Cg#C and Cg#CC sequences. In tokens of the Cg#C sequence, the mean HP of the SF C2 /g/ gesture was longer compared to the mean HP in tokens of the Cg#CC sequence. This was consistent in both normal and fast speech rates. However, when comparing the mean HP of the SF C2 /g/ gesture in /fatg#gal/ and /fatg#gdi:m/ in normal and fast speech rates, the mean HP duration exhibited a slight increase in the latter although the number of stops in SI position of the sequence increased.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
g#C	dag#tal	149.17	6	10.206	99.17	6	22.895
	dag#dam	124.17	6	14.634	101.67	6	17.795
	dag#kif	117.50	6	11.292	90.00	6	14.142
	dag#giʃ	88.33	6	11.690	76.67	6	5.164
Mean		**119.79**	**24**	**24.825**	**91.88**	**24**	**18.226**
g#CC	ʃag#tkasir	113.33	6	5.164	93.33	6	12.111
	hag#dkar	110.83	6	14.634	85.83	6	13.934
	nag#ktir	107.50	6	14.405	67.50	6	12.145
	hag#gdi:m	102.50	6	18.097	73.67	6	14.922
Mean		**108.54**	**24**	**13.632**	**80.08**	**24**	**16.157**
C**g**#C	fatg#tal	117.50	6	19.685	77.50	6	11.292
	fatg#dam	99.17	6	15.943	73.33	6	9.832
	fatg#kam	96.17	6	7.360	74.50	6	5.050
	fatg#gal	84.83	6	5.345	65.83	6	5.845
Mean		**99.42**	**24**	**17.350**	**72.79**	**24**	**8.997**
C**g**#CC	fatg#tkasir	64.17	6	22.675	74.17	6	3.764
	fatg#dkar	84.17	6	27.644	67.50	6	22.528

	fatg#ktir	75.83	6	37.605	36.67	6	4.082
	fatg#gdi:m	87.50	6	11.292	67.50	6	11.726
Mean		**77.92**	**24**	**26.413**	**61.46**	**24**	**19.195**

Table 4.4 Mean HP duration of SF /g/ normal and fast speech rate

The decrease in the duration of the SF single articulatory gesture stop can be highlighted in the HP duration of SF single articulatory TB gesture /g/ in /dag#tal/ and /ʃag#tkasir/ (figure 4.3 and 4.4).

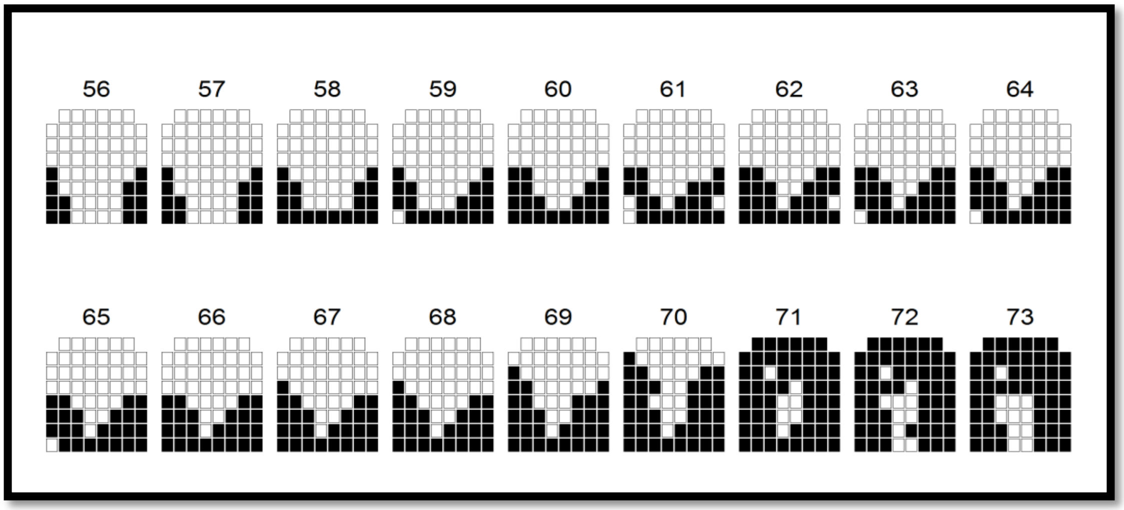


Figure 4.3 HP of SF single articulatory gesture /g/ in /dag#tal/ speaker 1 normal speech rate. Frames 58 to 71 show velar closure of about 140ms. Frame 71 shows overlap with alveolar /t/

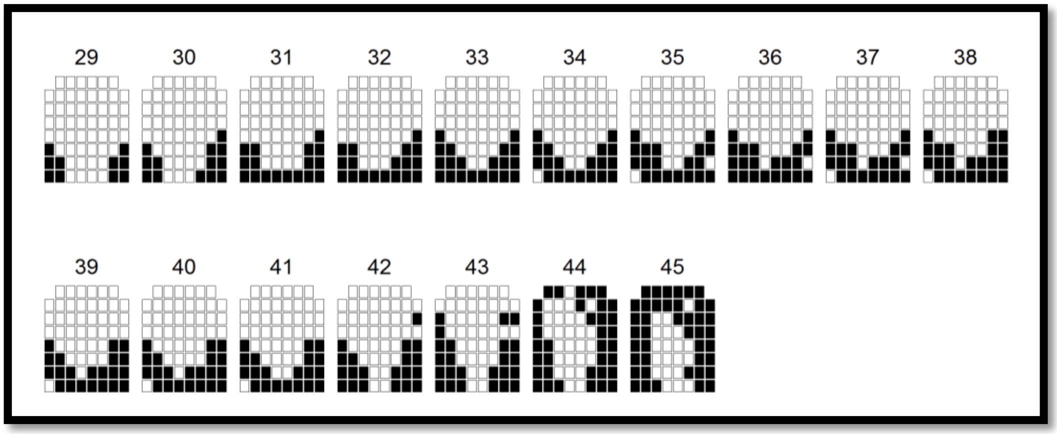


Figure 4.4 HP of SF single articulatory gesture /g/ in /ʃag#tkasir/ speaker 1 normal speech rate. Frames 31 to 41 show velar closure of approximately 110ms.

Individual speaker productions did not vary where both speakers also exhibited the same durational pattern. This decrease in the HP of SF /g/ as the number of stops in the sequence increases is highlighted in figure 4.5.

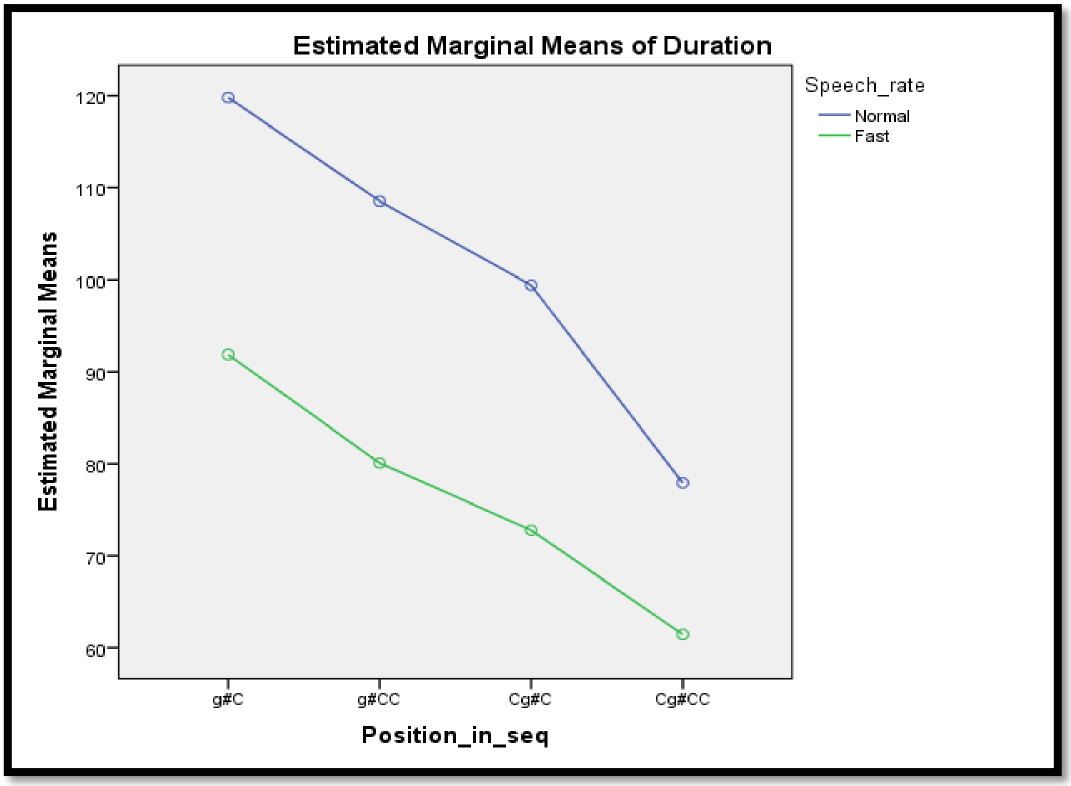


Figure 4.5 Mean durations of the HP of SF /g/ in the four sequence positions

4.2.1.3 Summary

Articulatory behaviour from the EPG data reveals that in SF position, the timing of the stop adjacent to the word boundary decreases as the number of stops in the sequence increases. In most tokens, the timing of SF stops was inversely proportional to the number of stops in the sequence resulting in the compression of the HP of stop gestures. The general timing pattern of SF stops reveals that mean HP of the pseudo geminate SF single articulatory gesture stop in tokens of **C**#C decreases as the number of stops in SI position increase in tokens of the **C**#CC sequence. Similarly, the mean HP of C2 of the SF cluster in C**C**#C decreases when the number of stops increases in SI position as in the C**C**#CC sequence. However, a few exceptions are found in the results of section 4.2.2.1 regarding the TT /t/ gesture stop.

Another interesting result is that the pseudo geminate SF stops investigated in tokens of the **C**#C and **C**#CC sequences are longer when followed by a heterorganic stop. In other words, when followed by a conflicting gesture, the duration of the stops is longer than when followed by a homorganic stop. For example, in section 4.2.1.2, the mean HP duration of the SF stop /d/ in /ʃid#tal/ and /ʃid#dis/ averaged 126ms and 107ms respectively when followed by the same gesture in both examples. However, when followed by a conflicting gesture as in /ʃid#kif/ and /ʃid#giʃ/ where the TT gesture is followed by a TB /k/ and /g/ gesture, the mean HP of SF /d/ averaged 145ms and 150ms respectively.

Speech rate also played a role in the timing of SF stops. The increase in speech rate led to a general decrease in the HP of all SF stops investigated in comparison with the same positions in normal speech rate. The following section presents the results of the counterpart SI stops /t,d,k,g/.

4.2.2 The influence of the number of stops in a sequence on the timing of SI stops

In this section, the results of the timing of SI stops /t,d,k,g/ in four positions are presented. The first two positions occur as SI singletons in tokens of the C#**C** and CC#**C** sequences, the other two occur as C1 of the SI cluster in tokens of the C#**C**C and CC#**C**C sequences.

4.2.2.1 SI alveolar /t/ and /d/

The EPG results reveal that in both normal and fast speech rates, the mean HP duration of SI TT /t/ gesture in the C#**t** sequence was longest when preceded by a single articulatory stop gesture averaging 134ms and 98ms respectively. This duration decreased to 85ms and 69ms respectively in the CC#**t** sequence. However, the results indicate that when occurring as C1 of the SI cluster in C#**t**C sequence, the mean HP duration of the TT gesture did not exhibit a similar decrease as the number of stops increased in SF position in tokens of the CC#**t**C sequence. The only tokens that did exhibit a decrease were found in /bat#tkasir/ and /ʃag#tkasir/ of the C#**t**C sequence. The mean HP duration of SI C2 /t/ in all the other tokens of the C#**t**C sequence increased when preceded by a SF cluster in tokens of the CC#**t**C sequence.

Sequence	**Token**	**Normal**			**Fast**		
		Mean(ms)	**N**	**Std. Dev.**	**Mean(ms)**	**N**	**Std.Dev.**
C#**t**	ʒit#tal	111.67	6	10.328	89.17	6	19.343
	ʃid#tal	126.67	6	16.021	94.17	6	15.303
	fak#tal	150.83	6	11.143	113.33	6	14.720
	dag#tal	149.17	6	10.206	99.17	6	22.895
Mean		**134.58**	**24**	**20.158**	**98.96**	**24**	**19.448**
CC#**t**	wagt#tal	97.00	6	12.329	75.50	6	10.932
	ʕagd#tal	88.17	6	10.028	71.67	6	7.528
	hatk#tal	76.67	6	13.292	71.67	6	6.831
	fatg#tal	80.00	6	14.832	60.00	6	11.402
Mean		**85.46**	**24**	**14.344**	**69.71**	**24**	**10.585**
C#**t**C	bat#tkasir	79.17	6	36.799	41.67	6	14.024
	ʃad#tkasir	52.50	6	9.354	58.83	6	7.627
	fak#tkasir	57.50	6	23.611	49.17	6	14.289
	ʃag#tkasir	69.17	6	10.685	50.83	6	10.206
Mean		**64.58**	**24**	**23.907**	**50.13**	**24**	**12.698**
CC#**t**C	wagt#tkasir	59.17	6	17.151	43.33	6	6.055
	ʕagd#tkasir	70.00	6	11.402	67.50	6	14.405
	hatk#tkasir	70.00	6	17.607	62.50	6	12.550
	fatg#tkasir	67.50	6	6.892	54.17	6	9.704
Mean		**66.67**	**24**	**13.805**	**56.88**	**24**	**13.973**

Table 4.5 Mean HP duration of SI /t/ at normal and fast speech rates

At normal speech rate, results also show that the mean HP duration of SI TT /d/ gesture decreased as the number of consonants adjacent to the word boundary increased when occurring as a singleton in C#**d** and CC#**d** sequences where the mean HP was

94ms and 76ms respectively. However, not all tokens were consistent with the general pattern. When comparing the mean HP duration of the TT /d/ gesture in /dag#dam/ and counterpart /fatg#dam/ in normal speech rate, the mean HP of SI /d/ was longer when preceded by a SF cluster averaging 84ms in /fatg#dam/. On the other hand, this pattern did not occur across all tokens when comparing the mean HP of SI C1 /d/ in the C#**d**C and CC#**d**C sequences. Here the mean HP exhibited a slight increase of 4ms in the CC#**d**C sequence (table 4.6). The mean HP duration of SF C1 /d/ in /nat#dkar/ and /ʃad#dkar/ of the C#**d**C sequence both increased in the corresponding /wagt#dkar/ and /ʕagd#dkar/ tokens of the CC#**d**C sequence. Contrary to this, the mean HP of SI C1 /d/ in /hag#dkar/ and /fak#dkar/ of the C#dC sequence exhibited a decrease when occurring in the corresponding /hatk#dkar/ and /fatg#dkar/ tokens of the CC#**d**C sequence.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**d**	ʒit#dis	104.17	6	10.685	4.17	6	15.626
	ʃid#dis	107.50	6	22.749	79.17	6	7.360
	fak#dam	88.33	6	28.752	92.50	6	27.884
	dag#dam	79.17	6	6.646	62.50	6	20.676
Mean		**94.79**	**24**	**21.593**	**79.58**	**24**	**21.260**
CC#**d**	wagt#daf	73.33	6	8.756	63.67	6	5.538
	ʕagd#dam	73.67	6	3.830	68.33	6	8.959
	hatk#dam	75.00	6	7.746	52.50	6	10.840
	fatg#dam	84.17	6	9.704	56.67	6	4.082
Mean		**76.54**	**24**	**8.602**	**60.29**	**24**	**9.612**
C#**d**C	nat#dkar	70.00	6	10.488	68.33	6	9.309
	ʃad#dkar	61.67	6	6.055	59.17	6	7.360
	fak#dkar	73.33	6	4.082	82.50	6	17.819
	hag#dkar	75.00	6	4.472	70.83	6	9.704
Mean		**70.00**	**24**	**8.209**	**70.21**	**24**	**13.869**
CC#**d**C	wagt#dkar	77.50	6	16.956	68.33	6	14.376
	ʕagd#dkar	77.50	6	8.803	73.33	6	20.166

	hatk#dkar	69.17	6	13.934	69.17	6	18.280
	fatg#dkar	72.50	6	12.145	63.33	6	15.384
Mean		**74.17**	**24**	**12.910**	**68.54**	**24**	**16.450**

Table 4.6 Mean HP duration of SI /d/ at normal and fast speech rates

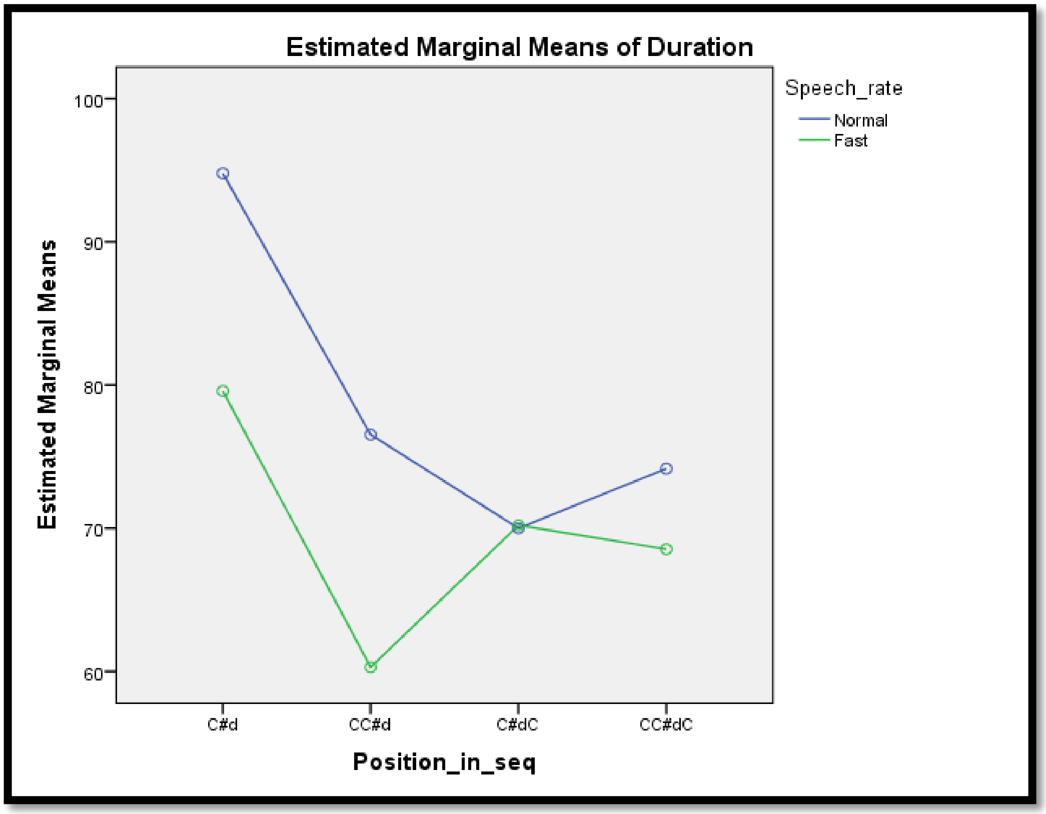


Figure 4.6 Mean durations of the HP of SI /d/ in the four sequence positions

4.2.2.2 SI velar /k/ and /g/

In terms of the relationship between timing and number of stops in the sequence, the mean HP duration of SI /k/ reveals that when occurring as a singleton, the mean HP duration decreases as the number of stops increases in SF position. The mean HP duration in tokens of the C#**k** sequence averaged 132ms in normal and 112ms in fast speech rates when preceded by a singleton stop. As the number of stops in SF position increased in tokens of the CC#**k** sequence, this decreased to 100ms and 75ms respectively.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
C#**k**	ʒit#kalb	136.67	6	33.714	136.67	6	37.103
	ʃid#kif	160.83	6	40.548	111.67	6	24.014
	fak#kif	113.33	6	7.528	111.67	6	24.014
	dag#kif	117.50	6	11.292	90.00	6	14.142
Mean		**132.08**	**24**	**31.825**	**112.50**	**24**	**29.635**
CC#**k**	wagt#kif	104.17	6	23.327	63.33	6	21.134
	ʕagd#kam	108.33	6	16.330	87.67	6	39.073
	hatk#kif	95.00	6	14.142	71.67	6	4.082
	fatg#kam	96.17	6	7.360	81.17	6	4.491
Mean		**100.92**	**24**	**16.237**	**75.96**	**24**	**22.939**
C#**k**C	nat#kdab	73.83	6	20.351	63.33	6	11.690
	ʃad#ktir	93.33	6	21.602	75.00	6	10.954
	fak#ktir	92.50	6	16.355	66.67	6	10.801
	nag#ktir	90.83	6	12.416	69.17	6	7.360
Mean		**86.88**	**24**	**19.326**	**68.54**	**24**	**10.579**
CC#**k**C	wagt#ktab	71.67	6	11.690	67.50	6	24.850
	ʕagd#ktab	53.33	6	8.165	65.00	6	18.708
	hatk#ktir	75.83	6	18.280	68.33	6	22.286
	fatg#ktir	79.17	6	17.440	57.50	6	15.083
Mean		**70.00**	**24**	**16.940**	**64.58**	**24**	**19.667**

Table 4.7 Mean HP duration of SI /k/ normal and fast speech rate

Furthermore, the mean HP duration of SI C1 /k/ also exhibited a similar decrease when comparing the mean HP in the C#**k**C and CC#**k**C sequences. However, results also indicate that variations between individual speaker productions occurred. At the fast speech rate of speaker 1, the mean HP duration of SI C1 /k/ in tokens of the CC#**k**C sequence increased to 81ms compared to tokens of the C#**k**C sequence where it averaged 72ms. This was not consistent with the general pattern where the mean HP continued to decrease as the number of stops in the sequence increased. The general pattern of the mean HP of /k/ in different sequence types is further highlighted in figure 4.7.

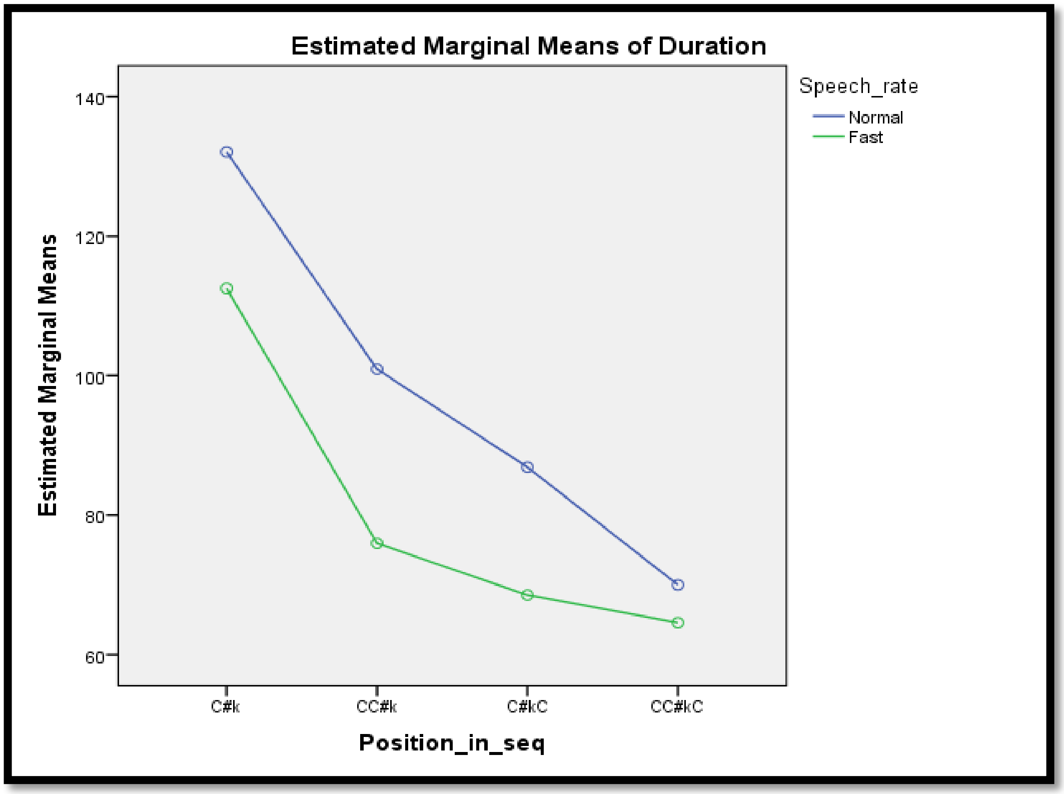


Figure 4.7 Mean durations of the HP of SI /k/ in the four sequence positions

On the other hand, results of the C#**g** and CC#**g** sequences also show that the mean HP of SI /g/ was shorter when preceded by a SF cluster than when preceded by a SF single articulatory gesture stop. In tokens of the C#**g** sequence, the mean HP duration of SI /g/ was 115ms in normal and 98ms in fast speech rate. This decreased to 81ms and 65ms when preceded by a SF cluster in tokens of the CC#**g** sequence. This further indicates the decrease in the HP as the number of stops in the sequence increases (table 4.8).

The mean HP duration of SI C1 /g/ in tokens of the C#**g**C and CC#**g**C sequences also exhibited a similar pattern. The mean HP of SI C1 /g/ was shorter in tokens of the CC#**g**C sequence compared to the mean HP duration in the counterpart C#**g**C sequence tokens where it was preceded by a singleton stop gesture. However, the only exception was the increase in fast speech rate in the mean HP duration of SI C1 /g/ found in /wagt#gdi:m/ where it averaged 80ms compared to the mean HP duration of SI C1 /g/ in the counterpart token /nat#gtal/ of the C#**g**C sequence where it averaged 72ms.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**g**	ʒit#giʃ	128.33	6	36.423	124.17	6	35.835
	ʃid#giʃ	119.17	6	20.595	104.17	6	20.104
	fak#giʃ	120.33	6	15.449	88.67	6	6.218
	dag#giʃ	95.00	6	21.679	76.67	6	5.164
Mean		**115.71**	**24**	**26.397**	**98.42**	**24**	**26.665**
CC#**g**	wagt#giʃ	86.67	6	37.771	65.00	6	22.361
	ʕagd#gas	76.67	6	16.931	52.50	6	8.216
	hatk#giʃ	76.17	6	10.685	70.83	6	16.857
	fatg#gal	84.83	6	5.345	73.33	6	5.164
Mean		**81.08**	**24**	**20.656**	**65.42**	**24**	**16.078**
C#**g**C	nat#gtal	85.83	6	10.685	72.50	6	18.641
	ʃad#gtal	115.83	6	33.379	82.50	6	12.145
	fak#gtal	86.67	6	12.111	86.67	6	18.619
	hag#gdi:m	91.67	6	28.752	88.33	6	32.042
Mean		**95.00**	**24**	**25.195**	**82.50**	**24**	**21.110**
CC#**g**C	wagt#gdi:m	81.67	6	32.506	80.83	6	41.523
	ʕagd#gdi:m	66.67	6	9.309	77.50	6	38.046
	hatk#gdi:m	73.33	6	19.408	75.00	6	28.636
	fatg#gdi:m	77.50	6	18.371	77.50	6	32.977
Mean		**74.79**	**24**	**20.876**	**77.71**	**24**	**33.296**

Table 4.8 Mean HP duration of SI /g/ at normal and fast speech rates

4.2.2.3 Summary

In SI position, the mean duration pattern of the stop adjacent to the word boundary exhibits a decrease in duration as the number of stops in the sequence increased. This was evident when comparing the SI singleton in both the C#**C** and CC#**C** sequences. In the latter where a SF cluster precedes it, the mean HP of the SI stop exhibited a decrease in duration ranging between 24ms-50ms in normal speech rate. This result is similar to the results of the SF stops investigated in section 4.2.1. Stop gestures are compressed in order to accommodate the increase in the number of stops. At both normal and fast speech rates, the longest HP duration of SI stops occurred in the C#**C** sequence.

Despite this, when comparing the mean HP duration of the SI C1 in the C#**C**C and CC#**C**C sequences, the pattern was not consistent. Some tokens did exhibit a decrease in the mean HP duration as the number of stops increased in SF position. Here the decrease ranged between 14ms-16ms. However, this decrease was less than that exhibited when comparing the mean HP duration of the SI singleton in C#**C** and CC#**C** sequences. Furthermore, some tokens actually exhibited an increase in the mean HP duration of the SI C1 stop under investigation in tokens of the CC#**C**C sequence compared to the same stop in the counterpart tokens in the CC#**C** sequence.

Having found a relationship between the timing of stops adjacent to the word boundary and the number of stops in a sequence, the following section presents the results of the effect of the number of stops on the timing of SF and SI clusters as a whole.

4.2.3 The influence of the number of stops on the timing of SF stop clusters

This section presents the results of the mean duration of SF clusters adjacent to the word boundary, i.e. the articulatory behaviour of SF cluster in tokens of the **CC**#C and **CC**#CC sequences. These results shed light on the effect the number of stops in SI position have on the timing of SF clusters. The duration of each cluster is identified as the interval between the first EPG frame showing complete closure of C1 of the cluster and the last EPG frame showing complete closure of C2 prior to the release and includes any ICI duration.

4.2.3.1 SF dorsal-coronal /gt/ and /gd/ clusters

The results in table 4.9 indicate that the mean duration of the SF cluster /gt/ decreases as the number of stops in SI position increases. At normal speech rate, the mean duration of /gt/ averaged 183ms in the **gt**#C sequence and decreased to 132ms in the **gt**#CC sequence.

In section 4.2.1.1, the mean HP duration of SF C2 /t/ in the same **gt**#C sequence averaged 83ms and slightly decreased by 5ms when occurring in the **gt**#CC sequence. However, the significant decrease of 51ms in the mean SF /gt/ cluster duration indicates that the increase in the number of stops in the sequence does not only affect the SF stop adjacent to the word boundary but all segments of the SF cluster.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
gt#C	wagt#tal	179.17	6	11.583	141.33	6	17.512
	wagt#daf	187.50	6	12.550	146.17	6	21.217
	wagt#kif	195.00	6	24.698	129.17	6	20.595
	wagt#giʃ	172.50	6	17.536	135.83	6	32.158
Mean		**183.54**	**24**	**18.385**	**138.13**	**24**	**22.878**
gt#CC	wagt#tkasir	120.00	6	14.491	87.50	6	11.726
	wagt#dkar	135.83	6	17.151	94.17	6	14.289
	wagt#ktab	137.50	6	19.937	100.83	6	15.943
	wagt#gdi:m	136.67	6	13.292	110.83	6	21.075
Mean		**132.50**	**24**	**17.004**	**98.33**	**24**	**17.425**

Table 4.9Mean duration of SF /gt/ cluster at normal and fast speech rates

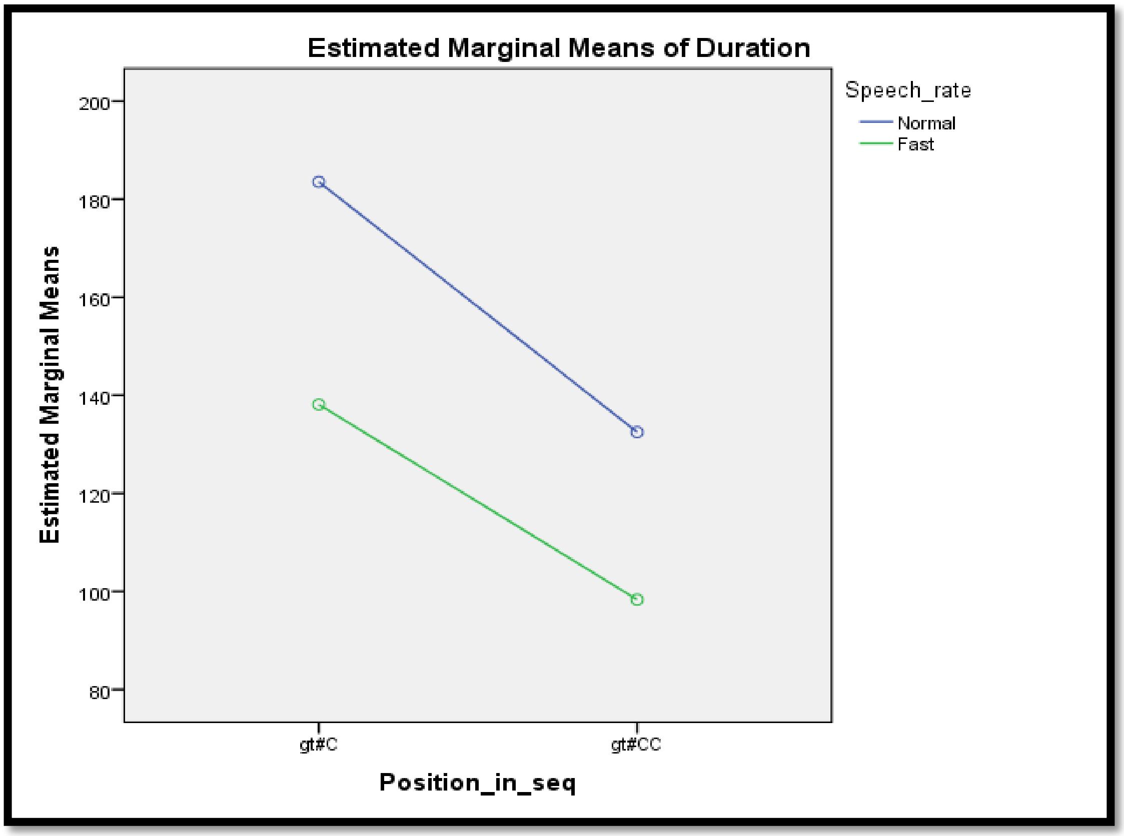


Figure 4.8 Mean duration of SF cluster /gt/ in two sequence positions

The same duration decrease pattern is also exhibited by the SF /gd/ cluster (table 4.10). At normal speech rate, the mean duration of the SF /gd/ cluster averaged 193ms when followed by a SI singleton in tokens of the **gd**#C sequence. The duration decreased to 163ms as a result of the increase in the number of stops in the SI position in tokens of the **gd**#CC sequence.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
gd#C	ʕagd#tal	208.17	6	21.830	158.33	6	23.805
	ʕagd#dam	190.83	6	5.845	169.17	6	28.562
	ʕagd#kam	180.83	6	21.311	170.00	6	37.148
	ʕagd#gas	193.50	6	35.826	134.17	6	18.819
Mean		**193.33**	**24**	**24.261**	**157.92**	**24**	**29.930**
gd#CC	ʕagd#tkasir	158.33	6	21.602	120.00	6	25.298
	ʕagd#dkar	156.67	6	18.074	95.00	6	10.954
	ʕagd#ktab	151.67	6	33.862	125.00	6	42.071
	ʕagd#gdi:m	189.17	6	37.339	120.00	6	15.492
Mean		**163.96**	**24**	**30.857**	**115.00**	**24**	**27.307**

Table 4.10 Mean duration of SF /gd/ cluster at normal and fast speech rates

The average decrease duration was 30ms at normal speech rate and 42ms at fast speech rate. In section 4.2.1.2, the mean HP duration of SF C2 /d/ in the **gd**#C sequence decreased by only 6ms at normal speech rate from 82ms to 76ms when followed by a SI cluster in the **gd**#CC sequence. The decrease in the mean duration of the whole SF /gd/ cluster here is considerably higher averaging 30ms for the normal speech rate.

4.2.3.2 SF coronal-dorsal /tk/ and /tg/ clusters

The results reveal that the durational pattern of SF coronal-dorsal clusters /tk/ and /tg/ were similar to the dorsal-coronal SF clusters in the previous section. The SF cluster /tk/ duration decreases as the number of stops in onset position increases. The mean SF cluster /tk/ duration was shorter in tokens of the **tk**#CC sequence averaging 152ms in the normal speech rate compared to 203ms in tokens of the **tk**#C sequence (table 4.11).

In fast speech rate, the decrease in the duration of the SF cluster was considerably lower. In comparing the mean duration of the SF /tk/ cluster in the tk#C and tk#CC sequences, the mean duration decreased by only 13ms.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
tk#C	hatk#tal	201.33	6	20.992	141.67	6	7.528
	hatk#dam	208.33	6	28.402	159.17	6	28.358
	hatk#kif	215.00	6	17.029	161.67	6	9.832
	hatk#giʃ	191.17	6	5.845	160.83	6	13.934
Mean		**203.96**	**24**	**20.565**	**155.83**	**24**	**17.917**
tk#CC	hatk#tkasir	175.00	6	40.125	120.83	6	15.303
	hatk#dkar	125.83	6	17.440	150.83	6	29.397
	hatk#ktir	152.50	6	38.955	141.67	6	45.789
	hatk#gdi:m	157.50	6	49.472	155.83	6	62.643
Mean		**152.71**	**24**	**40.027**	**142.29**	**24**	**41.650**

Table 4.11 Mean duration of SF /tk/ cluster at normal and fast speech rates

The highest decrease in mean SF cluster as a result of the increase in the number of stops in the sequence occurred in the SF /tg/ cluster. When followed by a SI singleton, the mean duration of SF cluster /**gt**/ in tokens of the **gt**#C sequence averaged 216ms at normal speech rate. This decreased to 155ms in tokens of the **tg**#CC sequence due to the increase in the number of stops in the adjacent SI position. The same durational pattern is exhibited for the fast speech rate where a decrease of 35ms occurred (table 4.12).

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
tg#C	fa**tg**#tal	228.33	6	22.061	165.83	6	17.151
	fa**tg**#dam	216.67	6	11.690	155.00	6	15.166
	fa**tg**#kam	214.50	6	13.546	168.67	6	17.049
	fa**tg**#gal	207.33	6	11.708	165.00	6	4.472
Mean		**216.71**	**4**	**16.268**	**163.62**	**24**	**14.467**
tg#CC	fa**tg**#tkasir	148.33	6	16.633	144.17	6	38.134
	fa**tg**#dkar	162.50	6	41.079	120.83	6	7.360
	fa**tg**#ktir	170.00	6	44.833	122.50	6	13.323
	fa**tg**#gdi:m	140.83	6	28.534	127.50	6	33.279
Mean		**155.42**	**24**	**34.323**	**128.75**	**24**	**26.386**

Table 4.12 Mean duration of SF /tg/ cluster at normal and fast speech rates

The decrease in duration in this SF cluster also indicates that the increase in the number of stops in the sequence affects all constituents of the SF cluster and is not limited to the SF stop adjacent to the word boundary. In section 4.2.1.4, the decrease in the mean HP duration of C2 /g/ of the SF cluster from **tg**#C to **tg**#CC sequences was 22ms at normal speech rate and 11ms at fast speech rate which is significantly less than the decrease found in the whole SF /tg/ cluster.

4.2.3.3 Summary

When followed by a SI singleton in the **CC**#C sequence, the duration of dorsal-coronal and coronal-dorsal SF clusters investigated were longer in duration than when followed by a SI cluster in the **CC**#CC sequence. At normal speech rate, this decrease ranged from 30-51ms. This pattern was also exhibited at fast speech rates. However, the decrease ranged from 13-42ms.

The results in section 4.2 show that C2 of the SF cluster in C**C**#C sequence decreases when followed by a SI cluster in the C**C**#CC sequence. However, the mean decrease duration was found to be significantly less and at times negligible compared to the decrease occurring in the whole SF cluster in this section as the number of stops increased in SI position. This is a clear indication that the increase in the number of stops in SI position does not only influence the duration of SF C2 as noted in section 4.2. Furthermore, these results indicate that SF clusters are variable in terms of their duration which could be due to changes in gestural coordination patterns between stops of SF clusters in tokens of different sequence types.

4.2.4 The influence of the number of stops on the timing of SI stop clusters

This section presents results of the mean duration of SI clusters adjacent to the word boundary, i.e. the timing of the SI cluster in tokens of the C#**CC** and CC#**CC** sequences. These results shed light on the effect the number of stops in SF position have on the timing of these clusters and therefore their production.

4.2.4.1 SI coronal-dorsal /tk/ and /dk/ clusters

The mean duration of the SI cluster /tk/ did not vary considerably as a result of the increase in the number of stops in SF position (table 4.13). At normal speech rate, the mean duration of the SI cluster when preceded by a singleton stop in the C#**tk** sequence averaged 141ms. When preceded by a SF cluster, the mean duration slightly decreased averaging 134ms. In fast speech rate on the other hand, results show that the mean duration of the SI cluster /tk/ in fact increased when preceded by a SF cluster in the CC#**tk** sequence averaging 121ms.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**tk**	bat#**tk**asir	149.83	6	40.990	106.67	6	14.720
	ʃad#**tk**asir	132.17	6	17.034	123.83	6	31.846
	fak#**tk**asir	146.33	6	42.387	109.17	6	12.416

	ʃag#**tk**asir	138.33	6	19.664	117.50	6	8.803
Mean		**141.67**	**24**	**30.862**	**114.29**	**24**	**19.141**
CC#**tk**	wagt#**tk**asir	126.67	6	14.376	115.83	6	11.583
	ʕagd#**tk**asir	142.50	6	12.145	130.83	6	15.943
	hatk#**tk**asir	132.50	6	17.248	122.50	6	19.429
	fatg#**tk**asir	137.50	6	4.183	117.50	6	8.216
Mean		**134.79**	**24**	**13.471**	**121.67**	**24**	**14.720**

Table 4.13 Mean duration of SI /tk/ at normal and fast speech rates

The amount of decrease in the duration of the SI cluster as the number of stops increased in SF position is considerably shorter than the amount exhibited by SF clusters as a result of the increase in the number of stops in SI position found in section 4.4. The mean decrease in duration of SI /tk/ cluster ranged between 1ms and 23ms at normal speech rate. This is evident in the difference between the SI cluster /tk/ in /bat#tkasir/ of the C#**tk** sequence and /hatk#tkasir/ of the CC#**tk** sequence (figures 4.9 and 4.10).

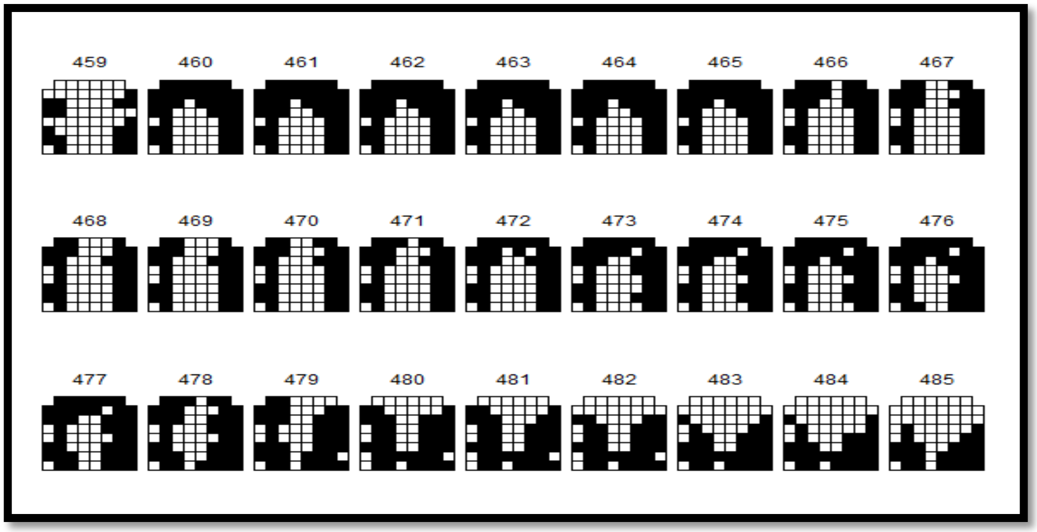


Figure 4.9 SI /tk/ cluster in /bat#tkasir/ speaker 1 normal speech rate. Frames 472 to 484 show duration of about 130ms. Frames 478 to 479 show an ICI duration of about 20ms. Frames 460 to 465 show coronal closure of SF alveolar /t/. Frames 472 to 477 show coronal closure of SI /t/.

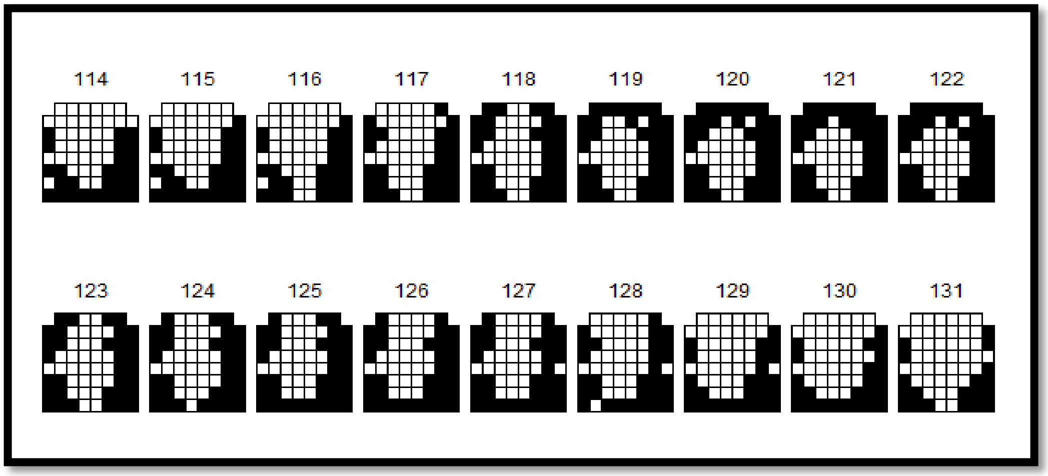


Figure 4.10 SI /tk/ cluster in /hatk#tkasir/ speaker 1 normal speech rate. Frames 119 to 130 show duration of about 120ms. Frames 123 to 124 show an ICI duration of about 20ms

The results also show that the mean duration of the SI /dk/ cluster decreased slightly when preceded by a SF cluster in normal speech rate (table 4.14). When preceded by a singleton stop in tokens of the C#**dk** sequence, the mean duration averaged 164ms and decreased to 147ms when preceded by a SF cluster in tokens of the CC#**dk** sequence. However, at fast speech rate there was no considerable variation exhibited as the number of stops increased in the preceding SF position.

Not all tokens exhibited the same durational pattern. The mean duration of SI /dk/ cluster in /nat#**dk**ar/ of the C#**dk** sequence averaged 155ms in normal speech rate when preceded by singleton stop /t/. As opposed to the decrease exhibited by the other tokens investigated, the mean duration of SI /dk/ increased to 160ms in counterpart /wagt#dkar/ of the CC#**dk** sequence as the number of stops in SF position increased when preceded by the SF /gt/ cluster.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
C#**dk**	nat#**dk**ar	155.00	6	6.325	113.83	6	39.550
	ʃad#**dk**ar	171.67	6	27.869	130.83	6	10.206
	fak#**dk**ar	163.33	6	8.756	148.33	6	9.309
	hag#**dk**ar	167.50	6	26.220	135.83	6	13.934
Mean		**164.37**	**24**	**19.578**	**132.21**	**24**	**24.157**
CC#**dk**	wagt#**dk**ar	160.00	6	15.811	135.00	6	21.909
	ʕagd#**dk**ar	155.83	6	15.303	125.00	6	22.804
	hatk#**dk**ar	135.00	6	19.235	148.33	6	12.111
	fatg#**dk**ar	140.83	6	9.174	130.00	6	8.367
Mean		**147.92**	**24**	**17.749**	**134.58**	**24**	**18.528**

Table 4.14 Mean duration of SI /dk/ cluster normal and fast speech rate

4.2.4.2 SI dorsal-coronal /kt/ and /gd/ clusters

The durational pattern exhibited by the dorsal-coronal SI /kt/ cluster was more consistent as presented in Table 4.15. In both speech rates the mean duration of the cluster decreased as a result of the increase in the number of stops in SF position. At normal speech rate, the mean duration of SI /kt/ averaged 183ms when preceded by a singleton stop in tokens of the C#**kt** sequence and decreased to 159ms in tokens of the CC#**kt** sequence. The results show a similar pattern at the fast speech rate.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean(ms)	N	Std. Dev.
C#**kt**	ʃad#**kt**ir	176.67	6	25.820	141.67	6	6.055
	fak#**kt**ir	194.17	6	22.004	135.00	6	17.029
	nag#**kt**ir	179.17	6	9.174	145.00	6	23.875
Mean		**183.33**	**18**	**20.651**	**140.56**	**18**	**16.794**
CC#**kt**	wagt#**kt**ab	160.00	6	20.000	139.17	6	3.764
	ʕagd#**kt**ab	151.67	6	16.330	130.83	6	3.764
	hatk#**kt**ir	161.67	6	12.910	136.67	6	10.801
	fatg#**kt**ir	165.83	6	18.552	122.50	6	16.047
Mean		**159.79**	**24**	**16.842**	**132.29**	**24**	**11.419**

Table 4.15 Mean duration of SI /kt/ cluster at normal and fast speech rates

On the other hand, the mean duration of the SI /gd/ cluster was not highly affected by the increase in the number of stops in SF position as highlighted in table 4.16. At normal speech rate, the mean duration remained stable with a negligible decrease of 2ms. At fast speech rate, the decrease averaged 15ms. In fast speech rate, the decrease in mean duration in these tokens averaged 17ms.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
C#**gd**	hag#**gd**iːm	160.00	6	8.944	132.50	6	15.083
Mean		**160.00**	**6**	**8.944**	**132.50**	**6**	**15.083**
CC#**gd**	wagt#**gd**iːm	155.83	6	19.600	115.83	6	13.197
	ʕagd#**gd**iːm	158.33	6	16.330	110.83	6	9.704
	hatk#**gd**iːm	158.33	6	14.376	120.00	6	10.488
	fatg#**gd**iːm	160.83	6	13.934	123.33	6	13.292
Mean		**158.33**	**24**	**15.228**	**117.50**	**24**	**11.978**

Table 4.16 Mean duration of SI /gd/ cluster normal and fast speech rate

4.2.4.3 Summary

The influence of the increase in the number of stops in the sequence on the timing pattern of SI cluster was not as consistent as the timing exhibited by SF clusters. At normal speech rate, the mean durations of SI clusters /tk/, /dk/, /kt/, and /gd/ was slightly longer when occurring in the C#**CC** sequence preceded by a pseudo geminate SF single articulatory gesture stop than in the CC#**CC** sequence. However, the EPG data reveals that the decrease in duration occurring in SI clusters resulting from the increase in the number of stops in the sequence was relatively less than that found to occur in the SF clusters in section 4.4. Furthermore, in some cases the decrease was negligible as was found in the SI /tk/ cluster. As opposed to SF clusters in section 4.4, SI clusters are less variable in terms of their durations. It can be said that SI clusters exhibited more stability and were not highly affected by the increase in the number of stops in SF position. These timing results of the EPG data are to be further discussed in section 5.2.5.

4.3 Intergestural timing and patterns of gestural coordination in stop sequences

This section presents the results of the study of intergestural timing and patterns of gestural coordination in stop sequences aimed at addressing the second research question. The articulatory behaviour of stops is expressed in terms of the percentage of unmasked stop releases in the four sequence types in addition to ICI duration and distribution patterns. This section concludes with results of the effect of the place order of stops involved on gestural coordination as mentioned in the third research question.

An increase in the release of C1 between any two adjacent stop gestures C1C2 reveals a lack of stop closure overlap. The resulting presence of an ICI as highlighted by the EPG frames indicates less gestural coordination and open transition between gestures of adjacent stops whereas the presence of successive EPG frames with total closures as a result of gestural overlap together with the absence of releases highlight closer gestural coordination. The degree of gestural coordination is measured in terms of the temporal lag between release of C1 and C2 closure, i.e. the ICI duration. An ICI in the EPG analysis is identified as the interval between the first EPG frame showing an open oral tract following a stop closure to the last frame showing an open oral tract preceding the following stop.

4.3.1 Release percentages and gestural coordination

The main observation regarding the percentage of releases occurring across the word boundary is that different sequence types exhibit different intergestural coordination patterns reflected in the percentage of unmasked releases occurring between adjacent stops.

4.3.1.1 Release percentage of SF stop in C#C sequence

The EPG frames show that in the two-stop C#C sequence tokens, stop gestures are closely articulated. EPG frames indicate that in most tokens, complete overlap of stop closure occurs across the word boundary. Therefore, tighter gestural coordination is found between the SF single articulatory gesture stop and the following SI stop in tokens of this sequence. A significantly low unmasked release percentage of 16% occurred in both speech rates as seen in table 4.17.

In /ʒit#giʃ/ for example, the unmasked release percentage of the SF single articulatory gesture stop was 17% at normal speech rate. However, in /fak#tal/ and /fak#dam/ tokens where stops adjacent to the word boundary are in the DC place order of articulation, the unmasked release percentage was much higher averaging 100% and 66% respectively. In the /dag#dam/ token, the unmasked release percentage of the SF /g/ averaged 50% in both speech rates.

Furthermore, homorganic stop tokens spanning the word boundary were closely articulated where the unmasked release percentage across the word boundary in both speech rates was 0%. EPG frames in this position indicate that the HP of SF stop overlaps with the HP of the SI stop. In these homorganic sequence tokens, the concatenation of identical segments across the word boundary resulted in the production of juncture geminates as highlighted in figure 4.11.

	Normal			Fast		
Token	**# rls.**	**% rls.**	**N**	**# rls.**	**% rls.**	**N**
ʒit#tal	0	--	6	0	--	6
ʒit#dis	0	--	6	0	--	6
ʒit#kalb	0	--	6	0	--	6
ʒit#giʃ	1	17	6	1	17	6
ʃid#tal	0	--	6	0	--	6
ʃid#dis	0	--	6	0	--	6
ʃid#kif	0	--	6	1	17	6
ʃid#giʃ	0	--	6	1	17	6
fak#tal	6	100	6	4	66	6
fak#dam	4	66	6	5	83	6
fak#kif	0	--	6	0	--	6
fak#giʃ	0	--	6	0	--	6
dag#tal	1	17	6	0	--	6
dag#dam	3	50	6	3	50	6
dag#kif	0	--	6	0	--	6
dag#giʃ	0	--	6	0	--	6
Mean	**15**	**16%**	**96**	**15**	**16%**	**96**

Table 4.17 Number of unmasked SF releases across word boundary and percentages in C#C sequence tokens at normal and fast speech rates

All unmasked stop releases occurred in heterorganic sequences and mostly in the DC order of place articulation. However, in /ʒit#giʃ/ of the CD order of place of articulation, the unmasked release percentage of SF /t/ was 17% indicating that 5 tokens exhibited stop closure overlap. In heterorganic stop sequences spanning the word boundary such as /ʃid#kif/ and /ʃid#giʃ/ tokens, the increase in speech rate actually resulted in an increase in unmasked releases from 0% at normal speech rate to 17% at fast speech rate indicating a decrease in gestural coordination. On the other hand, in /dag#tal/, a decrease in unmasked release percentage at fast speech rate resulted in closer gestural overlap across the word boundary in all tokens compared to normal speech rate where 16% exhibited unmasked stop releases.

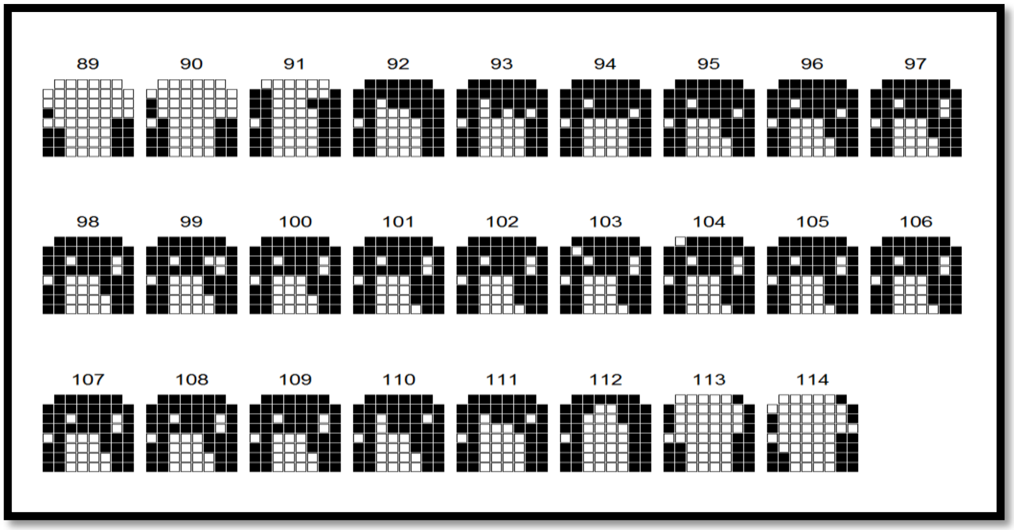


Figure 4.11 EPG frames showing fake geminate occurring in C#C sequence /ʒit#tal/ token by speaker 1 at normal speech rate. Frames 92 to 112 shows one alveolar /t/ HP of about 210ms spanning word boundary

4.3.1.2 Release percentage of stops in C#CC sequence

The EPG frames reveal different articulatory behaviour in the C#CC sequence tokens resulting in a different gestural coordination pattern across the word boundary. Results indicate a considerably higher unmasked release percentage of the SF single articulatory stop gesture before closure of SI C1 is formed. In this position, EPG frames reveal that 100% of the tokens resulted in unmasked stop releases in both normal and fast speech rates (table 4.18). Consisting of three stops in the sequence, which violates the total number of stops permitted by the syllabic template of TLA, the SF C2 was released prior to the formation of the HP of SI C1 in all the tokens and therefore none exhibited stop closure overlap.

	Normal					Fast				
Token	# rls	% rls.	SI rls	% rls.	N	# rls.	% rls.	SI rls.	% rls.	N
bat#tkasir	6	100	6	100	6	6	100	4	66	6
nat#dkar	6	100	4	66	6	6	100	4	66	6
nat#kdab	6	100	6	100	6	6	100	6	100	6
nat#gtal	6	100	6	100	6	6	100	4	66	6
ʃad#tkasir	6	100	6	100	6	6	100	3	50	6
ʃad#dkar	6	100	6	100	6	6	100	3	50	6
ʃad#ktir	6	100	5	83	6	6	100	4	66	6
ʃad#gtal	6	100	3	50	6	6	100	2	33	6
fak#tkasir	6	100	4	66	6	6	100	6	100	6
fak#dkar	6	100	5	83	6	6	100	3	50	6
fak#ktir	6	100	3	50	6	6	100	4	66	6
fak#gtal	6	100	3	50	6	6	100	3	50	6
ʃag#tkasir	6	100	3	50	6	6	100	4	66	6
hag#dkar	6	100	1	16	6	6	100	6	100	6
nag#ktir	6	100	3	50	6	6	100	3	50	6
hag#gdi:m	6	100	3	50	6	6	100	2	33	6
Mean	**96**	**100%**	**67**	**70%**	**96**	**96**	**100%**	**61**	**63%**	**96**

Table 4.18 Number of unmasked releases across word boundary and in SI cluster of C#CC sequence tokens at normal and fast speech rates

Due to the high percentage of unmasked releases, gestural coordination between the stops adjacent to the word boundary was very weak resulting in an ICI occurring at the word boundary. The unmasked release percentage of the SF stop remained stable at 100% for both speech rates. In comparison with the previous C#C sequence, weak gestural coordination across the word boundary in this three-stop sequence was also exhibited by tokens with homorganic sequences spanning the word boundary as in the /ʃad#dkar/ token in figure 4.12 as opposed to the gestural coordination pattern in the C#C sequence tokens where no releases occurred in homorganic tokens. The 100% unmasked release of the SF stop in the C#CC sequence occurred in all the tokens produced by both speakers in both normal and fast speech rates.

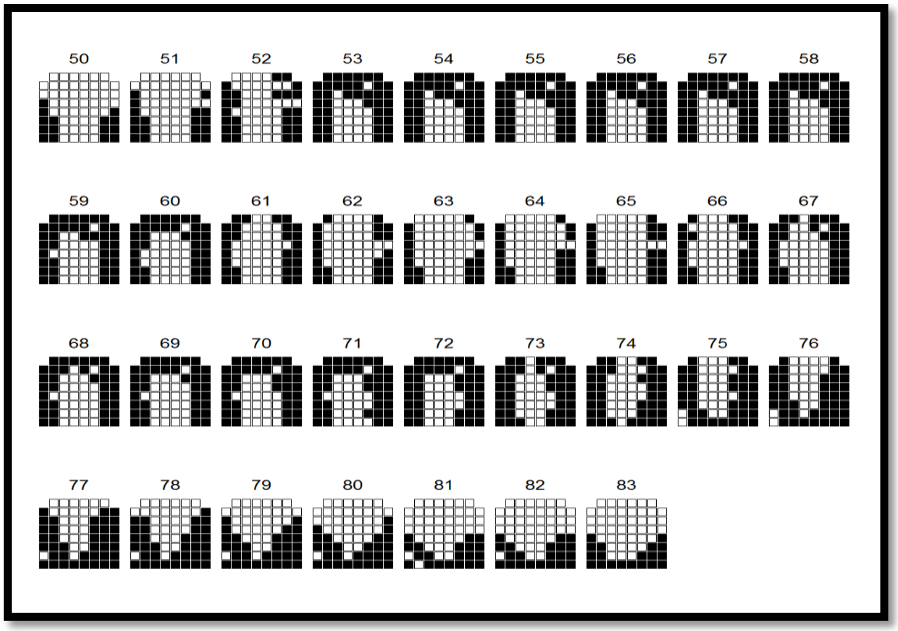


Figure 4.12 EPG frames showing release of SF /d/ at word boundary in C#CC homorganic sequence /ʃad#dkar/ by speaker 2 at normal speech rate. Frames 61 to 67 show ICI between the two alveolar closures

Furthermore, the results reveal closer gestural coordination between stop gestures in the SI cluster of the C#CC sequence. It is also worth mentioning that all SI clusters consist of heterorganic stops. Nevertheless, the unmasked release percentage of SI C1 decreased indicating closer gestural coordination in the SI cluster compared to the word boundary in the C#CC sequence tokens.

4.3.1.3 Release percentage of stops in CC#C sequence

The CC#C sequence tokens consisting of three stops like the C#CC sequence but with a different word boundary location exhibited a similar unmasked stop release pattern as the C#CC sequence. Both three-stop sequences exhibited tighter gestural coordination between their C1 and C2 stops and weak gestural coordination between their C2 and C3 stops. Table 4.19 compares the mean percentage release in both speech rates.

	Normal					**Fast**				
Token	**SF rls.**	**% rls.**	**# rls.**	**% rls.**	**N**	**SF rls.**	**% rls.**	**# rls.**	**% rls.**	**N**
wagt#tal	6	100	0	0	6	6	100	0	0	6
wagt#daf	6	100	0	0	6	6	100	0	0	6
wagt#kif	6	100	3	50	6	6	100	4	67	6
wagt#giʃ	6	100	3	50	6	6	100	3	50	6
ʕagd#tal	6	100	0	0	6	6	100	6	100	6
ʕagd#dam	6	100	0	0	6	6	100	6	100	6
ʕagd#kam	6	100	0	0	6	6	100	3	50	6
ʕagd#gas	6	100	3	50	6	6	100	6	100	6
hatk#tal	6	100	3	50	6	6	100	3	50	6
hatk#dam	6	100	6	100	6	6	100	6	100	6
hatk#kif	6	100	0	0	6	6	100	0	0	6
hatk#giʃ	6	100	0	0	6	6	100	0	0	6
fatg#tal	6	100	2	33	6	6	100	3	50	6
fatg#dam	6	100	2	33	6	6	100	5	83	6
fatg#kam	6	100	0	0	6	6	100	0	0	6
fatg#gal	6	100	0	0	6	6	100	0	0	6
Mean	**96**	**100%**	**22**	**23%**	**96**	**96**	**100%**	**33**	**34%**	**96**

Table 4.19 Number of unmasked releases in SF cluster and across word boundary of CC#C sequence tokens at normal and fast speech rates

This shows closer gestural coordination and overlap between stops occurring across the word boundary than across the word boundary of the C#CC sequence tokens in the previous section. As opposed to both the C#C and C#CC sequence tokens previously sequences investigated, the increase in speech rate resulted in a slight decrease in the percentage of unmasked releases of around 10% and therefore a relative increase in gestural overlapping as the gestures of stops spanning the word boundary are in close transition.

In all tokens where homorganic sequences across the word boundary occurred, the release of SF C2 was masked by the closure of the following SI stop indicating stop closure overlap. This high degree of gestural coordination is found in both speech rates. Consequently, the occurrence of ‘fake’ geminates in this sequence was very high, examples occurring in tokens such as /ʕagd#tal/, /fatg#gal/, and /hatk#kif/ as a result of total gestural overlap across the word boundary. Furthermore, an increase in gestural overlap was also exhibited in tokens consisting of heterorganic sequences spanning the word boundary.

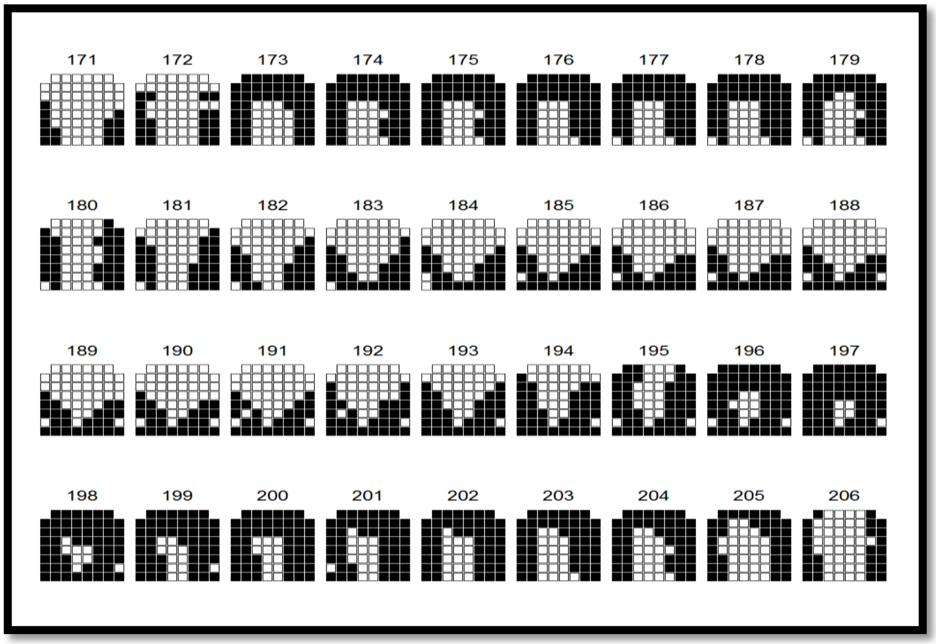


Figure 4.13 EPG frames showing lingual-palatal contact patterns in CC#C heterorganic sequence /fatg#tal/ by speaker 1 at normal speech rate. Frames 196 to 198 show across word boundary stop closure overlap of about 30ms

On the other hand, the results reveal that gestural coordination within the SF cluster of the CC#C sequence was very weak. In all the tokens produced, the HP of SF C1 was always released before the formation of SF C2 closure in both speech rates. The mean unmasked release percentage of SF C1 was 100% for both speech rates. This is also illustrated in figure 4.13 of /fatg#tal/ where SF C1 /t/ is released in frame 180 before SF C2 closure for /g/ is formed in frame 183. The gestural coordination pattern exhibited between stops of the SF cluster in the CC#C sequence is very similar to the pattern exhibited between stops across the word boundary in the C#CC sequence. As a result, tokens of this sequence exhibited tighter gestural coordination between stops spanning the word boundary than between stops in the SF cluster.

4.3.1.4 Release percentage of stops in CC#CC sequence

In the four-stop sequence CC#CC, the significantly high unmasked release exhibited by SF C2 as the stop gestures are pulled apart suggest that they are not closely coordinated across the word boundary. However, closer gestural coordination between SF and SI stops can be found as the mean unmasked release percentage of SF C1 and SI C1 decrease. Table 4.20 presents the results at normal speech rate.

	Normal						
Token	**SF rls**	**% rls**	**# rls**	**% rls**	**SI rls**	**% rls**	**N**
wagt#tkasir	5	83	6	100	6	100	6
wagt#dkar	3	50	6	100	3	50	6
wagt#ktab	3	50	6	100	3	50	6
wagt#gdi:m	3	50	6	100	3	50	6
ʕagd#tkasir	3	50	6	100	3	50	6
ʕagd#dkar	4	67	6	100	3	50	6
ʕagd#ktab	3	50	6	100	3	50	6
ʕagd#gdi:m	2	34	6	100	3	50	6
hatk#tkasir	6	100	6	100	3	50	6
hatk#dkar	4	67	6	100	1	17	6
hatk#ktir	2	34	6	100	4	67	6
hatk#gdim	3	50	6	100	3	50	6
fatg#tkasir	3	50	6	100	3	50	6
fatg#dkar	4	67	6	100	3	50	6
fatg#ktir	5	83	6	100	3	50	6
fatg#gdi:m	0	0	6	100	3	50	6
Mean	**53**	**55%**	**96**	**100%**	**50**	**52%**	**96**

Table 4.20 Number of unmasked releases between stops in SF cluster, across word boundary, and in SI cluster of CC#CC sequence tokens at normal speech rate

At normal speech rate, SF C2 was released before the formation of SI C1 in all the tokens produced which suggests that gestures are in open transition and stop closures did not overlap across the word boundary. As for the fast speech rate (table 4.21), the same gestural coordination pattern was exhibited although there was a negligible decrease in the mean unmasked release percentage of SF C2 which averaged almost 98%.

	Fast						
Token	**SF rls**	**% rls**	**# rls**	**% rls**	**SI rls**	**% rls**	**N**
wagt#tkasir	4	67	6	100	5	83	6
wagt#dkar	4	67	6	100	3	50	6
wagt#ktab	3	50	6	100	3	50	6
wagt#gdi:m	3	50	6	100	3	50	6
ʕagd#tkasir	3	50	4	67	3	50	6
ʕagd#dkar	3	50	6	100	4	67	6
ʕagd#ktab	2	33	6	100	3	50	6
ʕagd#gdi:m	2	33	6	100	3	50	6
hatk#tkasir	6	100	6	100	3	50	6
hatk#dkar	6	100	6	100	3	50	6
hatk#ktir	5	83	6	100	3	50	6
hatk#gdim	2	33	6	100	3	50	6
fatg#tkasir	3	50	6	100	3	50	6
fatg#dkar	3	50	6	100	3	50	6
fatg#ktir	6	100	6	100	3	50	6
fatg#gdi:m	4	67	6	100	3	50	6
Mean	**59**	**61%**	**94**	**98%**	**51**	**53%**	**96**

Table 4.21 Number of unmasked releases between stops in SF cluster, across word boundary, and in SI cluster of CC#CC sequence tokens at fast speech rate

The coordination pattern across the word boundary in the tokens of this sequence was very similar to the C#CC sequence. This result was anticipated due to the increase in the number of stops adjacent to the word boundary. The high percentage of unmasked stop releases occurred in the tokens of both homorganic and heterorganic sequences spanning the word boundary. The only exception occurred in the fast speech rate of the homorganic token /ʕagd#tkasir/ where there was a decrease in the release percentage to around 66% where 2 out of a total of 6 repetitions exhibited stop closure overlap across the word boundary.

The results of the unmasked release percentage within stops of the SF and SI clusters indicate a different gestural coordination pattern. At normal speech rate, closer gestural coordination between gestures of the SF cluster occurs as reflected in the decrease in the mean release percentage and therefore more stop closure overlap compared to the mean releases of SF C2. In SF position, 43 repetitions exhibited stop closure overlap out of 96 repetitions. A similar result for gestural coordination pattern is found between C1 and C2 stop in the SI cluster where the gestures are closely coordinated with each other as indicated by the decrease in the number of releases of SI C1. In this position, 46 repetitions out of 96 exhibited stop closure overlap. Both SF and SI clusters exhibited closer gestural coordination than across the word boundary in the CC#CC sequence. This decrease in the percentage of unmasked releases between stops of the SF and SI clusters is also exhibited at fast speech rate.

4.3.1.5 Statistical analysis

In order to identify any similarities in the pattern of stop releases occurring across the word boundaries of the four different sequence types, a one-way ANOVA test was carried out. The Shapiro-wilk test for normality showed a significant difference of $p>0.05$ and therefore normal distribution of the data. At normal speech rate, the one-way ANOVA showed a significant difference of $p<0.05$. Table 4.22 presents the results of the one-way ANOVA and Bonferroni Post Hoc that compares between groups to determine which specific group of variables is significantly different from the other.

The results of this test indicate that there was no significant difference between stop releases across the word boundary in the C#C and the CC#C sequence tokens in normal speech rate with a non-significant value of *p=0.427*. This shows that stop closure overlap patterns between stops adjacent to the word boundary in both these sequences were similar. Moreover, the results also show that stop releases across the word boundary in both C#C and the CC#C sequences was significantly different from stop releases across the word boundary in both the C#CC and CC#CC sequences with a significance value of *p=0.000*. However, no significant difference was found between stop releases across word boundary in the C#CC and CC#CC sequences with a significance value of *p=1.000*. As a result, two distinct categories in terms of stop releases across the word boundary were identified. The first category includes tokens of both the C#C and CC#C sequences where closer gestural coordination across the word boundary was exhibited. The second category includes tokens in both the C#CC and CC#CC sequences with less gestural coordination across the word boundary as found by the increase in stop releases in this position.

Multiple Comparisons

Dependent Variable: Release
Bonferroni

(I) Sequence type		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C#C	C#CC	.844*	.040	.000	.74	.95
	CC#C	.073	.040	.427	-.03	.18
	CC#CC	.844*	.040	.000	.74	.95
C#CC	C#C	-.844*	.040	.000	-.95	-.74
	CC#C	-.771*	.040	.000	-.88	-.66
	CC#CC	0.000	.040	1.000	-.11	.11
CC#C	C#C	-.073	.040	.427	-.18	.03
	C#CC	.771*	.040	.000	.66	.88
	CC#CC	.771*	.040	.000	.66	.88
CC#CC	C#C	-.844*	.040	.000	-.95	-.74
	C#CC	0.000	.040	1.000	-.11	.11
	CC#C	-.771*	.040	.000	-.88	-.66

***. The mean difference is significant at the 0.05 level.**

Table 4.22 Summary of significant effects in the Post Hoc statistical analysis of unmasked releases at word boundary in C#C, C#CC CC#C, and CC#CC sequences at normal speech rate

The same tests were also applied to stop release at fast speech rate. The Bonferroni Post Hoc test did not exhibit the same significant difference pattern between the four sequence types. Although no significant difference was found between stop releases across the word boundary in both the C#CC and CC#CC sequences with a significance value of $p=0.000$, contrary to the pattern in the normal speech rate, a significance value of $p=0.000$ was found between stop releases in the C#C and CC#C sequence tokens. Stop releases across the word boundary in the CC#C sequence on one hand was also significantly different from both the C#CC and CC#CC sequence tokens on the other hand with a significance value of $p=0.000$. This highlights the fact that although there was an increase in the release percentage across the word boundary in the CC#C sequence tokens which resulted in this being different from the C#C sequence tokens, the increase in release percentage was still less than in both the C#CC and CC#CC sequences. These results were also exhibited in the individual productions for each speaker.

4.3.1.6 Summary

The EPG results reveal that the gestural coordination pattern between adjacent stop gestures varied in the four sequence types as highlighted by the percentage of unmasked releases. Concerning coordination patterns across the word boundary, two different patterns emerged. Both the C#C and CC#C sequences exhibited closer gestural articulation reflected in the low percentage of unmasked releases and therefore more stop closure overlap. In both sequences, stop closure overlap between gestures of stops spanning the word boundary occurred in all the homorganic tokens. Tokens of the C#C sequence exhibited the lowest release percentage of the SF stop preceding the word boundary and as a result, stop gestures in this sequence were tightly coordinated.

On the other hand, the C#CC and CC#CC sequences exhibited a relative increase in the percentage of unmasked stop releases across the word boundaries in both sequences and therefore less stop closure overlap occurred. This was exhibited by both heterorganic and homorganic sequences spanning the word boundary. In both the C#CC and CC#CC sequences, close transition was not exhibited across the word boundary.

The stop release pattern between stops of the SF and SI clusters in the CC#C, C#CC, and CC#CC sequences differed. In the C#CC sequence, a high percentage of stop closure overlap was found between the stops of the SI cluster compared to the high percentage of unmasked stop releases and therefore open transitions between stops gestures across the word boundary. On the other hand, the CC#C sequence exhibited a high percentage of stop closure overlap across the word boundary but less within the SF cluster. Finally, the CC#CC sequence also exhibited weak coordination across the word boundary but relatively closer gestural coordination between stops of the SF and SI cluster compared to the SF and SI clusters of the CC#C and C#CC sequences.

The effect of the increase in speech rate on the release percentages was not consistent. In the CC#C sequence tokens, the increase in speech rate resulted in a decrease in stop closure overlap and therefore an increase in the percentage of releases. On the other hand, in the CC#CC sequence tokens, the increase in speech rate resulted in a slight increase in gestural coordination and closer transition between gestures spanning the word boundary reflected in the slight increase in stop closure overlap across the word boundary.

These results have highlighted the positions in which the articulatory coordination pattern of gestures is characterized by the lack of stop closure overlap in terms of stop gestures being released before closure formation of the following stop gesture. However, this does not imply that stop gestures are not coordinated with each other but simply indicates that the HP's do not overlap. The next section investigates the degree of gestural coordination between stops in terms of ICI durations. The duration of the ICI resulting from these releases provides further information on the degree of gestural coordination in terms of the lag duration between the release of a stop gesture and the closure of the following stop.

4.3.2 ICI durations and distribution patterns in stop sequences

Having already identified different gestural coordination patterns between stops in the four sequence types, this section presents the results of ICI durations for adjacent stops as a result of the unmasked releases previously detailed. The degree of gestural coordination is calculated in terms of the articulatory lag between release of C1 HP and C2 closure. Results of the durations of SF, SI, and word boundary ICIs for the four sequence types indicate the degree of gestural coordination between stops. The ICI duration between two stops is identified as the interval between the first EPG frame showing the release of C1 and the first EPG frame showing the closure of C2.

4.3.2.1 ICI duration and distribution in two-stop C#C sequence

Table 4.23 presents the results of the mean ICI duration occurring at the word boundary in the C#C sequence. EPG frames indicate that the ICI is relatively short for both speech rates as a result of closer gestural coordination across the word boundary between the SF and SI singleton stops. In normal speech rate, the mean ICI duration across all tokens averaged 13ms and remained almost stable at 12ms in fast speech rate. This indicates that the release of the SF stop is closely coordinated with the onset of the SI stop.

At normal speech rate, the shortest mean ICI duration is found in the /dag#tal/ token. Here the lag interval between the release of SF /g/ closure and the onset of the HP of the SI /t/ averaged 7ms. The longest lag interval occurred in the /fak#dam/ token with mean ICI duration occurring at the word boundary of 16ms. The /ʒit#giʃ/ token exhibited a mean ICI duration of 15ms. At fast speech rate, the mean ICI duration in both these tokens decreased to 12ms and 10ms respectively. The increase in speech rate resulted in a negligible decrease in the mean ICI duration in all the tokens except for the /dag#dam/ token where the mean word boundary ICI slightly increased from 10ms in the normal speech rate to 15ms in the fast speech rate. Furthermore, speaker 2 exhibited slightly shorter mean ICI durations than speaker 1. At normal speech rate, the mean ICI duration of speaker 1 was 15ms whereas speaker 2 was 11ms. In fast speech rate, the mean ICI duration for both speakers was 12ms.

	Normal			**Fast**		
Token	**Mean ICI**	**N**	**Std. Dev.**	**Mean ICI**	**N**	**Std. Dev.**
ʒit#tal	--	0	--	--	0	--
ʒit#dis	--	0	--	--	0	--
ʒit#kalb	--	0	--	--	0	--
ʒit#giʃ	15ms	1	--	10ms	1	--
ʃid#tal	--	0	--	--	0	--
ʃid#dis	--	0	--	--	0	--
ʃid#kif	--	0	--	5ms	1	--
ʃid#giʃ	--	0	--	10ms	1	--
fak#tal	14ms	6	5	12ms	4	5
fak#dam	16ms	4	5	12ms	5	5
fak#kif	--	0	--	--	0	--
fak#giʃ	--	0	--	--	0	--
dag#tal	7ms	1	--	--	0	--
dag#dam	10ms	3	3	17ms	3	5
dag#kif	--	0	--	--	0	--
dag#giʃ	--	0	--	--	0	--
Total	**13ms**	**15**	**5**	**12ms**	**15**	**5**

Table 4.23 Mean ICI durations at word boundary of C#C sequence for normal and fast rates

4.3.2.2 ICI duration and distribution in three-stop C#CC sequence

In section 4.3.1.2, the SF stop was released in all tokens whereas SI C1 exhibited a decrease in the percentage release. By comparing the mean ICI duration in the two positions in table 4.24, closer gestural coordination is exhibited within the onset cluster than across the word boundary. The mean lag duration between the first EPG frame not showing total closure after the SF HP and the first EPG frame showing total closure of SI C1 was 55ms at normal rate and 44ms at fast rate. On the other hand, a decrease in the lag interval is found in the SI cluster of this sequence. Here the mean ICI duration was 22ms at normal rate and 17ms at fast rate.

	Normal						Fast					
Token	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std. Dev**	**Mean SI ICI**	**N**	**Std Dev**
bat#tkasir	64ms	6	11	13ms	6	4	60ms	6	11	17ms	4	5
nat#dkar	60ms	6	11	13ms	4	11	50ms	6	8	15ms	4	10
nat#kdab	40ms	6	10	24ms	6	12	37ms	6	10	21ms	6	12
nat#gtal	58ms	6	7	18ms	6	15	38ms	6	9	16ms	4	4
ʃad#tkasir	65ms	6	16	21ms	6	13	41ms	6	19	15ms	3	5
ʃad#dkar	67ms	6	10	14ms	6	5	50ms	6	10	23ms	3	10
ʃad#ktir	44ms	6	5	22ms	5	12	42ms	6	8	22ms	4	9
ʃad#gtal	42ms	6	15	36ms	3	5	40ms	6	12	20ms	2	7
fak#tkasir	60ms	6	13	20ms	4	11	35ms	6	8	5ms	6	0
fak#dkar	46ms	6	10	20ms	5	10	30ms	6	6	20ms	3	10
fak#ktir	71ms	6	11	33ms	3	15	51ms	6	2	18ms	4	6
fak#gtal	68ms	6	10	30ms	3	8	53ms	6	8	23ms	3	5
ʃag#tkasir	49ms	6	6	25ms	3	8	40ms	6	10	18ms	4	8
hag#dkar	32ms	6	7	20ms	1	--	30ms	6	6	8ms	6	2
nag#ktir	60ms	6	5	30ms	3	5	60ms	6	13	33ms	3	11
hag#gdi:m	55ms	6	11	36ms	3	2	55ms	6	15	22ms	2	3
Mean	**55ms**	**96**	**16**	**22ms**	**67**	**11**	**44ms**	**96**	**13**	**17ms**	**61**	**9**

Table 4.24 Mean ICI durations at word boundary and SI cluster of C#CC sequence at normal and fast rate

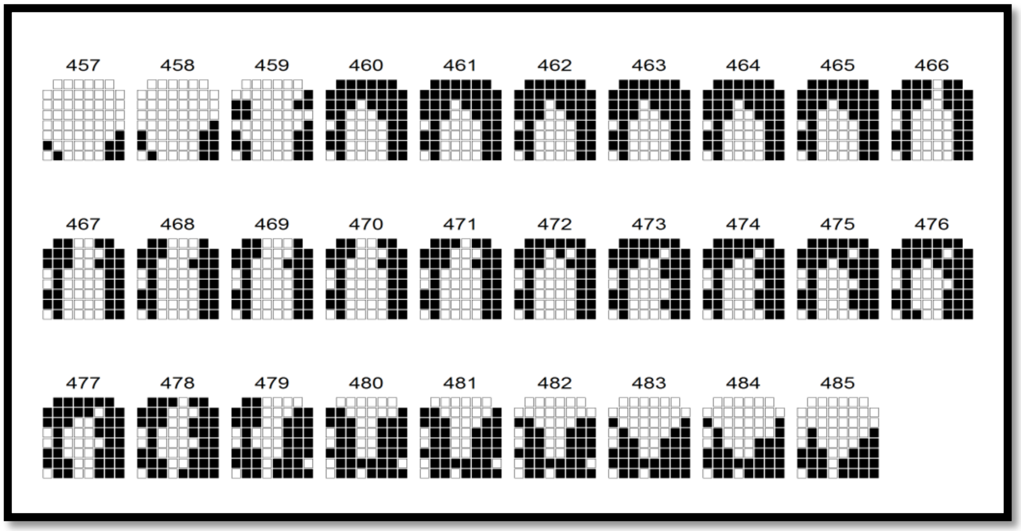


Figure 4.14 EPG frames showing lingual-palatal contact patterns in C#CC sequence /bat#tkasir/ by speaker 2 normal speech rate. Frames 466 to 471 show # ICI of about 60ms. Frames 478 to 479 show SI ICI between /t/ and /k/ of about 20ms.

4.3.2.3 ICI duration and distribution in three-stop CC#C sequence

Results of the mean duration of ICIs occurring in the CC#C sequence are presented in table 4.25.

	Normal						**Fast**					
Token	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SF ICI**	**N**	**Std. Dev**	**Mean # ICI**	**N**	**Std Dev**
wagt#tal	34ms	6	7	--	0	--	27ms	6	7	--	0	
wagt#daf	50ms	6	9	--	0	--	36ms	6	13	--	0	
wagt#kif	50ms	6	15	10ms	3	0	32ms	6	9	13ms	4	6
wagt#giʃ	52ms	6	11	31ms	3	10	39ms	6	9	23ms	3	2
ʕagd#tal	55ms	6	13	--	0	--	32ms	6	16	--	0	
ʕagd#dam	41ms	6	7	--	0	--	42ms	6	19	--	0	
ʕagd#kam	36ms	6	6	--	0	--	33ms	6	16	8ms	3	2
ʕagd#gas	41ms	6	5	13ms	3	5	25ms	6	10	10ms	6	0
hatk#tal	43ms	6	8	25ms	3	5	31ms	6	11	18ms	3	7
hatk#dam	48ms	6	12	21ms	6	13	31ms	6	5	20ms	6	11
hatk#kif	46ms	6	12	--	0	--	36ms	6	10	--	0	
hatk#giʃ	48ms	6	17	--	0	--	44ms	6	11	--	0	
fatg#tal	48ms	6	10	10ms	2	0	33ms	6	2	10ms	3	0
fatg#dam	53ms	6	15	15ms	2	7	34ms	6	5	10ms	5	0
fatg#kam	50ms	6	7	--	0	--	35ms	6	8	--	0	
fatg#gal	48ms	6	5	--	0	--	32ms	6	7	--	0	
Mean	**46ms**	**96**	**11**	**19ms**	**22**	**10**	**34ms**	**96**	**11**	**14ms**	**33**	**7**

Table 4.25 Mean ICI durations at SF cluster and word boundary of CC#C sequence at normal and fast rates

In terms of the number of stops in the sequence, both the CC#C and C#CC sequences presented in the previous section consist of three stops, C1C2C3. However, the main difference between both sequences is the location of the word boundary. Despite this difference, EPG frames reveal that the articulatory behaviour of these stops in both sequences is identical. They also indicate that the gestural coordination pattern between stops of the SF cluster was very weak as reflected in the mean SF ICI duration of 46ms at normal and 34ms at fast speech rate. Here the gestures are pulled apart resulting in a longer lag interval highlighted by the intervening ICI. On the other hand, stop gestures spanning the word boundary exhibited closer gestural coordination. At normal speech rate, the mean lag interval between SF C2 release and onset of closure of the SI stop was considerably shorter averaging 19ms at normal and 14ms at fast speech rates.

The same gestural coordination pattern was found in the individual productions of each speaker as presented in table 4.26. However, the mean lag intervals reveal that speaker one exhibited closer gestural coordination between stops in this sequence than speaker two.

	Normal						Fast					
Speaker	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SF ICI**	**N**	**Std. Dev**	**Mean # ICI**	**N**	**Std Dev**
Speaker 1	44ms	48	7	10ms	4	3	31ms	48	10	11ms	9	4
Speaker 2	50ms	48	15	21ms	18	11	37ms	48	11	15	24	8

Table 4.26 Mean ICI durations at SF cluster and word boundary of CC#C sequence at normal and fast rate for speaker 1 and 2

The similarity between the gestural coordination pattern exhibited in both three-stop sequences CC#C and C#CC is that there is more gestural lag between C1 and C2 in both sequences and therefore gestures are pulled apart rather than the lag exhibited by C2 and C3 of these sequences.

4.3.2.4 ICI duration and distribution in four-stop CC#CC sequence

Due to the increase in the number of stops, the EPG frames indicate that the articulatory behaviour of stop gestures in the CC#CC sequence differ from the previous stop sequences. At normal speech rate table 4.27, the mean ICI duration occurring within the SF cluster was 16ms. This indicates that SF stops are closely articulated where the lag duration between the release of SF C1 and onset of closure of SF C2 is very short. This pattern is not consistent with the pattern exhibited by tokens of the CC#C sequence where weak gestural coordination was found between SF C1 and C2. In some cases, the EPG frames also show that SF C1 is not released and both HP’s of SF C1 and C2 overlap as in the SF cluster /tg/ in the /fatg#gdi:m/ token. The longest mean lag duration between the EPG frame showing SF C1 release and onset of closure of SF C2 is found in the SF cluster /gd/ of /ʕagd#tkasir/ where the mean ICI duration was 26ms.

Results of gestural coordination across the word boundary show that stops adjacent to the word boundary in this sequence are not in close transition and gestures are further pulled apart as highlighted by the number of EPG frames with no lingual-palatal closures. Resulting ICI duration in this position are considerably longer, with a mean ICI duration of 56ms. In some examples, such as in /fatg#ktir/, the mean word boundary ICI duration is 80ms. Despite being homorganic, a relatively long lag duration can be found between SF C2 /g/ and SI C1 /k/ indicating that gestural coordination is very weak in this position. This is also evident in all other tokens where homorganic sequences occur across the word boundary. In fact, it can be seen that longer lag durations are exhibited by homorganic sequences across the word boundary than heterorganic sequences. In these sequence types, the ICI duration in normal speech rate ranged between 66ms and 80ms. In section 4.3.1.4 results reveal that SF C2 is released in all tokens.

The articulatory behaviour exhibited between stops of the SI cluster in the CC#CC sequence is similar to that exhibited by stops of the SF cluster. The EPG frames reveal that a relatively short lag duration is found between SI C1 and C2 with a mean of 21ms. Apart from the long lag duration of 40ms exhibited by the EPG frames between stops in the SI /kt/ cluster in /fatg#ktir/, lag duration here ranged from 8ms to 30ms, indicating closer gestural coordination within the SI cluster than between stops adjacent to the word boundary.

	Normal								
Token	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std. Dev**
wagt#tkasir	23ms	5	13	66ms	6	17	16ms	6	9
wagt#dkar	16ms	3	11	66ms	6	15	18ms	3	11
wagt#ktab	13ms	3	6	45ms	6	11	18ms	3	6
wagt#gdi:m	11ms	3	7	43ms	6	14	18ms	3	12
ʕagd#tkasir	26ms	3	18	64ms	6	6	25ms	3	13
ʕagd#dkar	13ms	4	11	68ms	6	6	8ms	3	3
ʕagd#ktab	21ms	3	14	40ms	6	16	26ms	3	11
ʕagd#gdi:m	12ms	2	3	40ms	6	20	23ms	3	6
hatk#tkasir	15ms	6	9	40ms	6	14	11ms	3	3
hatk#dkar	15ms	4	7	45ms	6	10	10ms	1	0
hatk#ktir	12ms	2	10	64ms	6	11	27ms	4	14
hatk#gdim	13ms	3	5	66ms	6	14	31ms	3	14
fatg#tkasir	15ms	3	8	50ms	6	12	15ms	3	5
fatg#dkar	11ms	4	2	47ms	6	21	15ms	3	5
fatg#ktir	10ms	5	0	80ms	6	16	41ms	3	3
fatg#gdi:m	--	--	--	77ms	6	12	36ms	3	10
Mean	**16ms**	**53**	**10**	**56ms**	**96**	**19**	**21ms**	**50**	**12**

Table 4.27 Mean ICI durations at SF cluster, word boundary, and SI cluster of CC#CC sequence at normal speech rate

The articulatory behaviour between stops in the CC#CC sequence was similar at the fast speech rate presented in table 4.28. The mean lag duration decreased as a result of the increase in speech rate indicating closer gestural coordination between adjacent stops in SF, word boundary, and SI position.

	Fast								
Token	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std. Dev**
wagt#tkasir	15ms	4	7	65ms	6	7	19ms	5	8
wagt#dkar	11ms	4	2	65ms	6	8	20ms	3	13
wagt#ktab	16ms	3	8	38ms	6	2	31ms	3	10
wagt#gdi:m	18ms	3	3	39ms	6	3	18ms	3	10
ʕagd#tkasir	8ms	3	6	55ms	4	10	15ms	3	0
ʕagd#dkar	13ms	3	3	45ms	6	15	8ms	3	2
ʕagd#ktab	17ms	2	3	34ms	6	5	26ms	3	7
ʕagd#gdi:m	20ms	2	7	40ms	6	10	18ms	3	10
hatk#tkasir	13ms	6	7	35ms	6	5	11ms	3	2
hatk#dkar	10ms	6	0	35ms	6	24	6ms	3	2
hatk#ktir	14ms	5	5	64ms	6	13	20ms	3	5
hatk#gdim	10ms	2	0	62ms	6	14	26ms	3	2
fatg#tkasir	11ms	3	3	36ms	6	10	6ms	3	2
fatg#dkar	10ms	3	0	41ms	6	19	16ms	3	11
fatg#ktir	14ms	6	5	76ms	6	3	30ms	3	0
fatg#gdi:m	7ms	4	3	64ms	6	10	21ms	3	10
Mean	**13ms**	**59**	**5**	**49ms**	**94**	**18**	**18ms**	**50**	**9**

Table 4.28 Mean ICI durations at SF cluster, word boundary, and SI cluster of CC#CC sequence fast speech rate

In brief, results indicate that gestures are more closely coordinated within SF and SI clusters than across the word boundary. This pattern is exhibited by both individual speaker productions. However, speaker one exhibited a closer gestural coordination pattern than speaker two as indicated in the shorter mean ICI duration in the productions of speaker one in tables 4.29 and 4.30.

	Normal								
Speaker	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std. Dev**
Speaker 1	9ms	14	1	47ms	48	16	9ms	5	2
Speaker 2	17ms	39	10	66ms	48	16	23ms	45	11

Table 4.29 Mean ICI durations at SF cluster, word boundary, and SI cluster of CC#CC sequence at normal speech rate for each speaker

	Fast								
Speaker	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std. Dev**
Speaker 1	12ms	17	4	41ms	46	17	10ms	4	0
Speaker 2	13ms	42	5	58ms	48	14	19ms	46	10

Table 4.30 Mean ICI durations at SF cluster, word boundary, and SI cluster of CC#CC sequence at normal speech rate for each speaker

4.3.2.5 Summary

The EPG data reveals different articulatory behaviour occurring between stops in the four sequence types investigated. Results of both section 4.3.1 and 4.3.2 are consistent in that longer ICIs occurred between stops exhibiting high release percentages. Gestural coordination patterns differ from one sequence to another depending on the number of stops in the sequence and the position of word boundary within the sequence. In the two-stop C#C sequence, stop gestures spanning the word boundary are tightly articulated as revealed by the high degree of overlap between these gestures in addition to the relatively short word boundary ICI with a mean of 13ms in tokens where the HP of both stops did not exhibit complete overlap. However, when the number of stops in the sequence exceeds two, the articulatory behaviour between adjacent stops in the sequence becomes complicated. The three-stop C#CC sequence exhibited close articulatory behaviour between stops of the SI cluster. Both stop gestures of the SI cluster were closely articulated with a mean ICI duration of 22ms indicating that the release of the HP of SI C1 is quickly succeeded by the closure of the articulators of SI C2. However, articulatory behaviour across the word boundary in this sequence reveals that gestural coordination is very weak. The mean ICI duration in this position was 55ms. This indicates that movement of the articulators is not in close transition and a longer lag duration intervenes between the release of the SF stop HP and onset of closure of SI C1.

Despite a different word boundary location, articulatory behaviour in the three-stop sequence CC#C was similar to the C#CC sequence. Both sequences consist of three stops C1, C2, and C3. Articulatory behaviour revealed by the EPG indicate that in the CC#C sequence, the articulators responsible for stops spanning the word boundary are closely coordinated and lag durations averaged 19ms. Further evidence for this is found in homorganic sequences occurring in this position where one long HP was found in the EPG frames signaling a lack of release at the word boundary. However, gestural coordination between stops of the SF cluster was very weak. Articulators responsible for closures of both stops were not closely coordinated resulting in relatively long lag duration between the release of the HP of SF C1 and onset of closure of SF C2. The mean lag duration at normal speech rate in this position was relatively long with an ICI averaging 46ms. This explains the results found in section 4.2.1 where the timing of the SF C2 in the C**C**#C sequence was shorter in duration than the SF stop in **C**#CC sequence. The longer ICI duration in the SF cluster of the **CC**#C sequence resulted in a decrease in the duration of the SF C2 following the ICI. The similarity in articulatory behaviour between the C#CC and CC#C sequence is that gestural coordination is very weak with long lag durations between C1 and C2 of both sequences. However, articulatory behaviour of C2 and C3 reveals that the articulators are closely synchronized resulting in relatively shorter lag durations.

Finally, the CC#CC sequence exhibits unique articulatory behaviour in terms of the gestural coordination patterns between stops especially in SF position. Tokens of this sequence reveal that articulators are closely coordinated during the HP of adjacent stops in both SF and SI clusters. Lag durations between the release of the articulator in SF C1 and closure for SF C2 are relatively short, averaging 16ms at normal speech rate compared to the lag duration between stops of the SF cluster in the CC#C sequence tokens, which averaged 46ms. The same gestural coordination pattern is found between stops of the SI cluster. Here the articulatory behaviour exhibited by the EPG frames reveals short lag durations between the release of the HP of SI C1 and onset of closure of SI C2. Articulators responsible for the production of stops in the SI cluster are closely coordinated exhibiting a short mean lag duration of 21ms at normal speech rate and 18ms at fast speech rate. As a result of the close coordination between articulators of the SF and SI clusters, a weak gestural coordination pattern was found between stops spanning the word boundary. A relatively long lag duration indicating weak gestural coordination is found across the word boundary similar to the articulatory behaviour found across the word boundary of the C#CC sequence and the SF cluster of the **CC**#C sequence. The mean lag duration here was 56ms at normal and 49ms at fast speech rate.

These results indicate that two distinct types of ICIs emerge. The first is a long ICI occurring where long lag is found between stop gestures. This type is typical of epenthetic vowel durations that occur in positions where gestural coordination is at its weakest. The second is a short ICI occurring where short lag is found between stop gestures. This type of ICI occurs in positions where closer gestural coordination between stop gestures was exhibited. The second type does not seem to be a true epenthetic vowel but has durations typical to “excrescent” vowels that are a result of the transition process between consonant articulations (Hall 2011).

Speech rate also had an effect on gestural coordination. In positions where long lag duration were found to occur, i.e. the word boundary of the C#CC sequence, the SF cluster of the CC#C sequence, and the word boundary of the CC#CC sequence, the lag duration decreased as the speech rate increased indicating closer gestural coordination at fast speech rate. However, in positions where short lag durations were found to occur i.e. the word boundary of the C#C sequence, the SI cluster of the C#CC sequence, and SF and SI clusters of the CC#CC sequence, the lag duration between HP’s was not affected. Here the increase in speech rate did not result in closer coordination between articulators as indicated by the negligible decrease in the lag durations. These results are also in line with the classification of Libyan Arabic as being a VC dialect (Kiparsky 2003, Watson 2007).

Having identified different gestural coordination patterns between stops in different sequences, the following section investigates the effect of the order of place of articulation on gestural coordination.

4.4 The influence of order of place of articulation on gestural coordination and overlapping

Two topics are dealt with in this section. Firstly, the results of the effect of the order of place of articulation as either coronal-dorsal (CD) vs. dorsal-coronal (DC) on the coarticulation of stop gestures spanning the word boundary are presented. The aim is to determine whether articulators exhibit closer gesture coordination and therefore closer transitions when a TT gesture is followed by a TB gesture order or vice versa. The degree of gestural coordination is measured in terms of the temporal overlap or lag between stop closures as highlighted by the EPG frames. The investigation is limited to the gestures of stops spanning the word boundary, which is the focus of this study. Secondly, the focus shifts to the effect of the order of place of articulation of the stops involved on stop closure overlap. This investigation is limited to CD and DC tokens where complete overlap was exhibited across the word boundary as revealed by the EPG frames. Since gestural overlap occurs in both CD and DC order of place of articulation, this section explores whether the amount of overlap is also affected by the place order of articulation. Homorganic sequences are excluded from both these investigations since the order of place of articulation is the same. Furthermore, in order to avoid any coarticulatory effects from tautosyllabic clusters on consonants adjacent to the word boundary, the CC#C, C#CC, and CC#CC sequence tokens were excluded due to the presence of tautosyllabic clusters in their sequences and only C#C sequence tokens are investigated. This part of the study addresses the third research question.

4.4.1 Influence of order of place of articulation on gestural coordination in the C#C sequence

Table 4.31 presents the data investigated according to the order of the place of articulation of the stops adjacent to the word boundary.

Sequence	Order of place of articulation	
	Coronal-to-dorsal (CD)	Dorsal-to-coronal (DC)
C#C	ʒit#kalb, ʒit#giʃ, ʃid#kif, ʃid#giʃ	fak#tal, fak#dam, dag#tal, dag#dam

Table 4.31 Tokens classified according to order of place of articulation of stops adjacent to the word boundary in C#C sequence

As previously mentioned in section 3.5, the overlap duration of the HP of two adjacent stop gestures C1C2 as indicated by the EPG frames is assigned a negative (-) value and the lag duration between the release of C1 and onset of closure of C2 is assigned a positive (+) value. The resulting value is considered to be a continuum (ICI/OV) where a high positive value indicates a decrease in the degree of gestural coordination for a particular order of articulation. On the other hand, a high negative value indicates closer gestural coordination and more overlap for a particular order of articulation.

The percentage of unmasked stop releases occurring across the word boundary in each order of place of articulation was investigated first. The results presented in table 4.32 indicate that the percentage of the unmasked release of SF single articulatory gesture stop in the C#C sequence tokens was higher in the DC order of place of articulation in both speech rates. Articulatory behaviour in the CD order shows that gestural overlap across the word boundary in this context is very high with only 4% of the tokens not exhibiting stop closure overlap at normal speech rate and 12% at fast speech rate. On the other hand, in the DC order of place of articulation, the movement of the articulators responsible for the stop gesture are not closely coordinated resulting in a high percentage of unmasked releases of the HP of the SF stop before the closure for the HP of the SI stop is reached. In this context, unmasked SF stop releases averaged 58% at normal and 50% at fast speech rate.

		Normal			**Fast**		
	Token	**# rls.**	**% rls.**	**N**	**# rls.**	**% rls.**	**N**
CD	ʒit#kalb	0	--	6	0	--	6
	ʒit#giʃ	1	17%	6	1	17%	6
	ʃid#kif	0	--	6	1	17%	6
	ʃid#giʃ	0	--	6	1	17%	6
	Total	**1**	**4%**	**24**	**3**	**12%**	**24**
DC	fak#tal	6	100%	6	4	66%	6
	fak#dam	4	66%	6	5	83%	6
	dag#tal	1	17%	6	0	--	6
	dag#dam	3	50%	6	3	50%	6
	Total	**14**	**58%**	**24**	**12**	**50%**	**24**

Table 4.32 Unmasked release percentages of SF stop in C#C sequence in CD and DC order of place of articulation

In terms of the ICI/OV duration, articulatory behaviour of stops adjacent to the word boundary indicates that gestures of the CD order of place of articulation are more closely coordinated than the DC order of place of articulation. Table 4.33 presents the results of the mean ICI/OV durations used to measure degrees of gestural coordination between stops in each order of place of articulation.

Token		**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Deviation**	**Mean (ms)**	**N**	**Std. Deviation**
CD	ʒit#kalb	-43ms	6	9.024	-48ms	6	10.079
	ʒit#giʃ	-31ms	6	8.975	-57ms	6	6.737
	ʃid#kif	-21ms	6	4.400	-31ms	6	11.819
	ʃid#giʃ	-36ms	6	9.174	-15ms	6	8.784
	Mean	**-33ms**	**24**	**9.759**	**-37ms**	**24**	**9.135**
DC	fak#tal	5ms	6	5.583	-7ms	6	7.583
	fak#dam	10ms	6	7.492	-7ms	6	5.111
	dag#tal	-23ms	6	8.605	-20ms	6	8.944
	dag#dam	1ms	6	7.206	0ms	6	10.974
	Mean	**-2ms**	**24**	**7.674**	**-8ms**	**24**	**8.750**

Table 4.33 Mean ICI/OV in C#C sequence in CD and DC order of place of articulation

All tokens of the CD order of place of articulation exhibited a negative mean ICI/OV indicating that the articulators are closely coordinated resulting in the overlap of stop closures. At normal speech rate, the mean ICI/OV is -33ms. At fast speech rate the mean is -37ms. The increase in speech rate resulted in a slight increase in the overlap duration and therefore closer gestural coordination. In the DC order of place of articulation, results show that stop gestures are pulled apart as indicated by the short ICI/OV mean of -2ms at normal speech rate and -8ms at fast speech rate. This indicates that the mean duration of stop closure overlap is shorter than in the CD context. For example, in /ʒit#kalb/ of the CD order of place of articulation in figure 4.15, the result of the degree of gestural coordination between the stop closure of the TT gesture of /t/ and TB gesture of /k/ averaged -41ms indicating more overlap duration. On the other hand, in /fak#tal/ of the DC context figure 4.16 where both stops under investigation are the same but in a different order of place of articulation, the degree of gestural coordination between the stop closure of the TB gesture of /k/ and the TT gesture of /t/ averaged 5ms. Since having a positive value due to the lag duration and resulting ICI, this shows that the gestures are not articulated in close coordination but are rather pulled apart. However, the only exception in this order of place of articulation is found in /dag#tal/. Here the mean ICI/OV was -23ms at normal speech rate and -20ms at fast speech rate indicating closer gestural coordination between the TB /g/ gesture and the TT /t/ in relation to other tokens of the DC order.

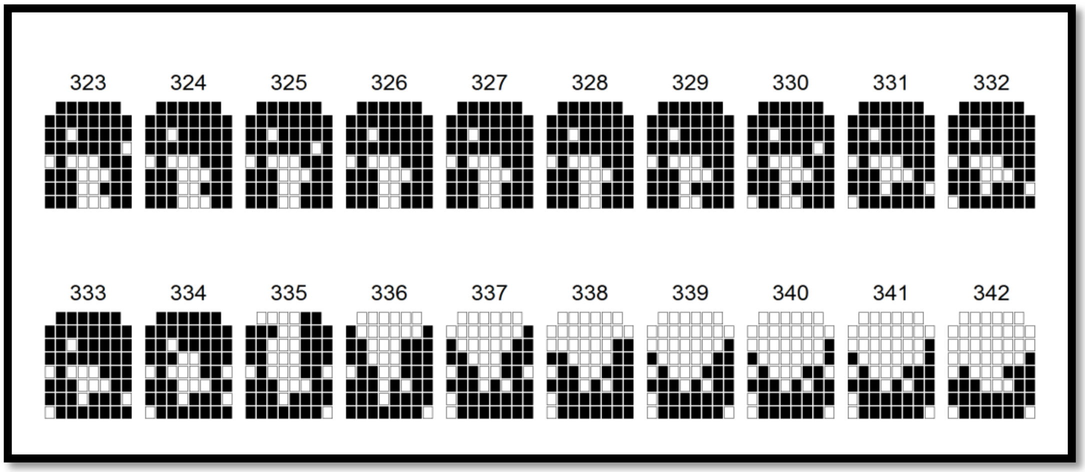


Figure 4.15 EPG frames showing lingual-palatal contact patterns in C#C sequence /ʒit#kalb/ speaker 1 normal speech rate. Frames 331 to 334 show stop closure overlap between TT and TB gestures of about 40ms

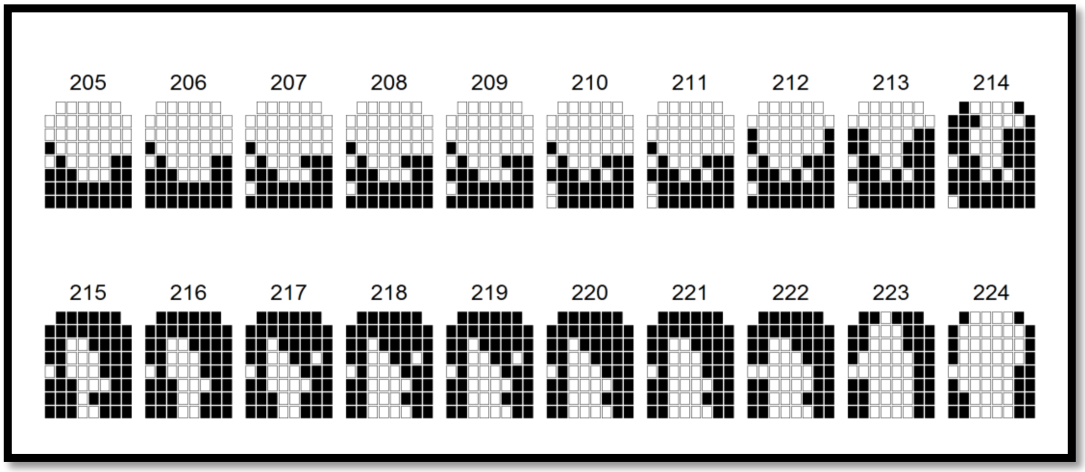


Figure 4.16 EPG frames showing lingual-palatal contact in C#C DC context token /fak#tal/ speaker 1 normal speech rate. Stop closures of the TB and TT gestures do not overlap

Results also reveal that in the CD order of articulation, tokens with voice agreement occurring across the word boundary exhibit the highest negative ICI/OV value and therefore relatively longer overlap durations. Examples of this were found in the token /ʒit#kalb/ where both stops spanning the word boundary were voiceless the ICI/OV duration averaged -43ms. Furthermore, in the token /ʃid#giʃ/ where both stops spanning the word boundary were voiced, the overlap ICI/OV averaged -36ms.

Both speakers exhibit the same articulatory behaviour pattern. However, speaker 2 exhibited closer gestural coordination than speaker 1 in both the CD and DC order of articulation of stops as highlighted by the mean ICI/OV durations in table 4.34.

		Normal			**Fast**		
		Mean (ms)	**N**	**Std. Deviation**	**Mean (ms)**	**N**	**Std. Deviation**
Speaker 1	**CD**	-26.67	12	17.880	-20.00	12	16.514
	DC	5.42	12	14.994	-2.50	12	17.645
Speaker 2	**CD**	-38.75	12	29.705	-55.00	12	38.671
	DC	-9.17	12	28.828	-14.58	12	28.079

Table 4.34 Mean ICI/OV in C#C sequence in CD and DC order of place of articulation for each speaker

4.4.1.1 Statistical analysis

Statistical tests were carried out to measure any significant differences between the CD and DC order of articulation. At normal speech rate, the Shapiro-Wilk normality tests show that the data was not normally distributed with a significance value of $p<0.05$. A Mann-Whitney U test was conducted to test for significant differences between the CD and DC contexts.

The Mann-Whitney U nonparametric test shows a significance value of $p<0.05$ between the CD and DC contexts across the word boundary in the C#C sequence. The same significant difference was found for speaker one at normal speech rate. However, results show that no significant difference between the CD and DC contexts in the productions of speaker 2 where the significance value was $p=0.063$.

At fast speech rate, data was normally distributed and an Independent sample T-test was carried out. The results shows a significant difference of $p<0.05$ between the total means for both speakers in the CD and DC order of articulation. The same significant difference between the CD and DC contexts was found in the individual productions of each speaker at fast speech rate. A significant difference between the mean in the CD context and DC context with a value of $p= 0.020$ was found in the fast speech rate of speaker 1. Similarly, a significant difference between the means with a value of $p= 0.008$ was found in the fast speech rate of speaker 2.

4.4.2 The influence of order of place of articulation on stop closure overlap durations

Results have so far confirmed that in terms of articulatory behaviour of stops, the temporal relations between gestures in the CD context exhibit closer gestural coordination than in the DC context. Since a number of tokens in the DC context also exhibited gestural overlap across the word boundary as highlighted in the results of section 4.3.1.1, this section investigates the effect of the order of place of articulation of the stops on total gestural overlapping across the word boundary. Tokens that did not exhibit complete overlapping of stop closures were excluded. Table 4.35 presents the results of the overlap duration between stop closures in the CD and DC contexts at both speech rates.

Token		Normal			Fast		
		Mean	**N**	**Std. Deviation**	**Mean**	**N**	**Std. Deviation**
CD	ʒit#kalb	43ms	6	14	47ms	6	8
	ʒit#giʃ	31ms	6	12	70ms	5	12
	ʃid#kif	21ms	6	7	38ms	5	7
	ʃid#giʃ	35ms	6	9	20ms	5	7
	Total	**32ms**	**24**	**24**	**44ms**	**21**	**31**
DC	fak#tal	40ms	1	0	47ms	2	10
	fak#dam	20ms	1	0	45ms	2	7
	dag#tal	38ms	4	6	20ms	6	8
	dag#dam	8ms	3	2	16ms	3	5
	Total	**26ms**	**9**	**21**	**27ms**	**13**	**15**

Table 4.35 Stop closure overlap durations in C#C sequence

The mean stop closure overlap duration was slightly longer in tokens of the CD order of place of articulation with a mean of 32ms at normal and 44ms at fast speech rate. Stop closure overlap durations are found to be slightly shorter in the DC order of place of articulation averaging 26ms at normal and 27ms at fast speech rate. At normal speech rate, in the CD context where a TT gesture is followed by a TB gesture, the mean overlap duration of both stop closures was highest in /ʒit#kalb/ where a TT gesture if followed by a TB gesture averaging 43ms in normal speech rate. The shortest mean stop closure overlap duration is exhibited by /ʃid#kif/ where the mean overlap duration of TT /d/ and TB /k/ averaged 21ms at normal speech rate. It is also clear that the increase in speech rate resulted in closer gestural coordination and therefore an increase in the overlap duration of stop closures. In the previous example /ʃid#kif/, the mean stop closure overlap increased to 38ms as a result of the increase in speech rate. The effect of the increase in speech rate is also visible in the stop closure overlap duration between the TT gesture and the TB gesture in /ʒit#giʃ/ where it averaged 31ms in normal speech rate and increased to 70ms at fast speech rate as a result of gestures sliding closer to each other.

Stop closure overlap duration was found to be slightly lower in the DC order of place of articulation. As a result of the decrease in gestural coordination between stops in the DC context as found in the previous section, stop gestures are slightly pulled apart when a TB gesture is followed by a TT gesture as indicated by the decrease in the stop closure overlap duration. The mean stop closure overlap duration in this context was 26ms at normal and 27ms at fast speech rate. Relatively long stop closure overlap durations are also found in this context. In normal speech rate, stop closure overlap durations between the TB gestures and the following TT gestures averaged 40ms and 38ms in /fak#tal/ and /dag#tal/ respectively. Furthermore, despite the increase in the overlap duration of stop closures as a result of the increase in speech rate, the increase in duration was not as significant as the increase in stop closure overlap as a result of the increase in speech rate exhibited by the CD tokens. The only exception was the increase in the mean stop closure overlap duration found in /fak#dam/ which at normal speech rate was 20ms, increasing to 45ms at fast speech rate.

Order of articulation		**Normal**			**Fast**		
		Mean	**N**	**Std. Deviation**	**Mean**	**N**	**Std. Deviation**
Coronal-to-dorsal	**Speaker 1**	27ms	12	17	26ms	10	9
	Speaker 2	39ms	12	29	60ms	11	35
Dorsal-to-coronal	**Speaker 1**	14ms	4	4	35ms	6	7
	Speaker 2	37ms	5	24	18ms	7	16

Table 4.36 Stop closure overlap durations in C#C sequence

The results in this section indicate that despite closer gestural coordination is exhibited by tokens of the CD order of place of articulation than those of the DC order of place of articulation, this does not suggest that more stop closure overlap is found in tokens of the CD context in comparison to the DC context.

4.4.3 The influence of overlap duration on sequence duration

This section presents the results of the effect the overlap duration has on the duration of stops in the C#C sequence. Results have so far identified that articulatory coordination and stop closure overlap durations in the C#C sequence are affected by the order of place of articulation context. This section presents the results of the relation between stop closure overlap durations and the duration of the stop sequence in C#C. Since gestures are more closely articulated, it is anticipated that the duration of the sequence will decrease as a result of the increase in stop closure overlap duration. Table 4.37 presents the results of the mean word boundary sequence duration in C#C and corresponding mean overlap duration between the SF and SI stop.

Token	**Normal**	
	Mean Seq. Duration C#C	**Mean Overlap duration**
dag#dam	205	8
fak#dam	235	20
dag#tal	236	38
ʃid#giʃ	270	35
ʒit#giʃ	275	40
ʒit#kalb	278	43
fak#tal	305	40
ʃid#kif	306	48

Table 4.37 Mean sequence (SF+SI stop) duration and overlap duration

Results reveal that there is no consistent relationship between the duration of the sequence and the duration of stop closure overlap. In most cases, an increase in stop closure overlap duration seems to occur with an increase in the total C#C sequence duration. For example, in /dag#tal/, the mean SF and SI stop sequence duration was 236ms and the stop closure overlap duration averaged 38ms. On the other hand, the stop closure overlap duration increased to 40ms in /fak#tal/ where the mean sequence duration averaged 305ms. However, figure 4.17 shows that in the /ʃid#kif/ phrase, the stop closure overlap duration sometimes decreases as the duration of the sequence increases.

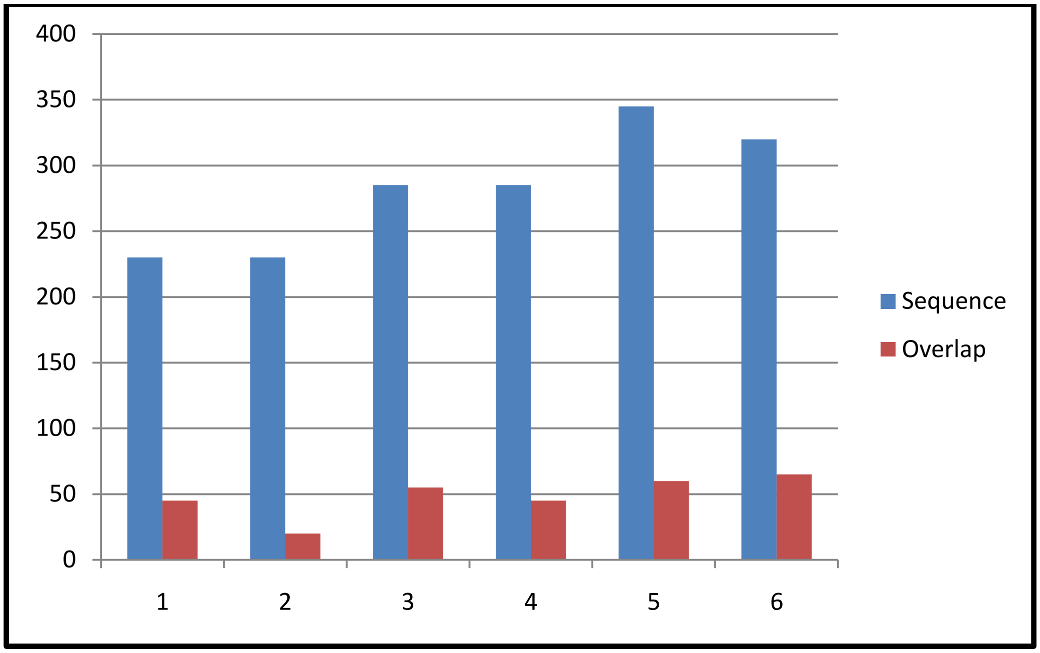


Figure 4.17 /t#g/ sequence duration and gestural overlap duration in 6 reptitions of /ʒit#giʃ/ highlighting lack of correlation

4.4.4 Summary

The results reveal that in the C#C sequence tokens, more unmasked SF stop releases are found in the DC than in the CD order of place of articulation. This indicates that more stop closure overlapping across the word boundary occurred in the CD context rather than the DC context. The increase in speech rate did not however result in a decrease in the release percentage in both contexts. In fact, unmasked releases of the SF stop increased slightly as speech rate increased in the CD context.

In terms of articulatory coordination, tokens following the CD order of place of articulation showed significantly closer gestural coordination across the word boundary than tokens following the DC order. A TT gesture exhibited closer gestural coordination with a following TB gesture. In the DC order of place of articulation, articulatory movement is not tightly coordinated. Although stop closure overlap is also exhibited across the word boundary in some tokens of the DC order of place of articulation, the ICI/OV was significantly different than in the DC context. In other words, a TB gesture is not closely coordinated with a following TT gesture. Furthermore, closer gestural coordination and longer overlap durations are found to occur between stops of the CD context that agree in voicing. However this pattern did not occur at fast speech rate or in the DC order of place of articulation.

In both CD and DC order of place of articulation, closer articulatory coordination occurred as a result of the increase in speech rate. More stop closure overlap duration and shorter lag durations between stop gestures are exhibited in tokens of both orders of place of articulation. However, the increase in the degree of gestural coordination between stops was relatively greater in the CD order of place of articulation.

The effect of the order of place of articulation of stops spanning the word boundary on stop closure overlap durations has revealed that stop closure overlap across the word boundary in the CD order of articulation does not differ considerably from the DC order of articulation. Despite closer gestural coordination in terms of lag durations and overlap durations being exhibited by tokens of the CD order of place of articulation than the DC order of place of articulation, the results suggest that stop closure overlap in tokens of the CD and DC context is consistent.

Furthermore, the results also indicate that there is no inverse relation between sequence duration and stop closure overlap duration. It was anticipated that the duration of the sequence decreases as a result of the increase in stop closure overlap duration. However, the relation between both durations is not consistent.

The overlap durations revealed by the EPG results of section 4.4.1 and 4.4.2 are to be used for the purpose of inferring overlap durations in the acoustic data analysis in Chapter five particularly in C#C sequence tokens. However, in the acoustics data, it is not possible to infer overlap durations from sequence duration as revealed by results of section 4.4.3. These results are to be further discussed in section 5.4.4.

4.5 Overall summary of EPG results

This section presents an overall summary of the results of the EPG data. The results are further discussed in light of the literature review along with relevant sections of the acoustics data in Chapter five. In terms of the timing of stops in SF and SI positions adjacent to the word boundary, results indicate that segment timing relations are not confined to SI and SF stops or syllables but also spread across word boundaries. This was particularly evident in the effect of the number of stops in a sequence had on the timing SF and SI stop singletons. The results of both sections 4.2.1 and 4.2.2 reveal that the HP's of SF and SI stops decrease as the number of stops in a sequence increases. The duration of stops adjacent to the word boundary whether occurring as singletons or within a SF or SI cluster, tends to decrease as the number of stops increase on the other side of the word boundary. The timing of the SF and SI stops in **C**#C and C#**C** respectively exhibit a decrease in their durations when followed or preceded by clusters in **C**#CC and CC#**C** respectively. However, this pattern is more consistent and evident in SF stops investigated where SF stops were more variable than their counterpart SI stops. Furthermore, SF stops of the **C**#C and **C**#CC sequences were in most cases relatively longer in duration than their counterpart SI stops of the C#**C** and CC#**C** sequences. This is due to the pseudo-geminate nature of the former. However, when occurring as C2 of a SF cluster or C1 of a SI cluster as in tokens of the C**C**#C and C#**C**C respectively, the timing pattern of these stops was not consistent as the number of stops increased. For example, the SF C2 occurring in tokens of the C**C**#C sequence did not exhibit a stable decrease in duration when the same stop occurs in tokens of the C**C**#CC sequence. Likewise, the SI C1 in tokens of the C#**C**C sequence did not exhibit a stable decrease in duration pattern when the same stop occurs in tokens of the CC#**C**C sequence.

The results of the timing of SF clusters investigated in section 4.2.3 indicate a consistent decrease in their durations as the number of stops increased across the word boundary in SI position. However, the decrease in the timing of SI clusters as the number of stops increased in the adjacent SF position was relatively less than that exhibited by SF clusters and in some cases negligible as found in section 4.2.4. The decrease in the timing of SF clusters in the **CC**#C is relatively higher ranging between 30ms to 51ms as the number of stops increased in SI position in the **CC**#CC sequence. This is due to different gestural coordination patterns exhibited by stops of the SF cluster in the **CC**#C sand **CC**#CC sequences found in sections 4.3.2.3 and 4.3.2.4. The lag duration and therefore the ICI between stops of the SF cluster in **CC**#CC is considerably shorter than the ICI occurring between stops of the SF cluster in **CC**#C sequence. On the other hand, the decrease in the timing of the SI cluster in C#**CC** ranged between 7ms and 19ms as the number of stops increased in the SF position in the CC#**CC** sequence. ICI distribution patterns in sections 4.3.2.2 and 4.3.2.4 reveal that the SI clusters in both C#**CC** and CC#**CC** sequences exhibit tighter gestural coordination patterns and therefore shorter ICI durations in both sequences. SI stops and clusters exhibited more stability whereas SF stops and clusters were more variable due to different gestural coordination patterns in the SF cluster in tokens of the **CC**#C and **CC**#CC sequences. The results here are in line with these studies that SF clusters exhibit less gestural coordination and are more variable in timing in comparison with SI clusters (Browman & Goldstein 1988, 2000; Marin & Pouplier 2002; Byrd 2003; Gafos 2002).

The effect of speech rate was found to be consistent throughout the timing results. Articulatory timing was directly affected by the increase in speech rate. As the speech rate increased, the HP duration of the individual stops generally decreases. The SF and SI clusters also exhibited this effect. The durations of SF and SI cluster types also decreased as a result of the increase in speech rate. This is due to the increase in the velocity of the articulators therefore resulting in shorter HP durations. These timing results exhibited by the EPG data are to be used in inferring durational measurements in the acoustics data especially in cases where the HP of a following stop overlaps the HP of the stop preceding it. In such cases, the lack of the presence of the acoustic release burst on the waveform and spectrogram means that making durational measurements is very difficult.

Section 4.3 reveals that articulatory coordination patterns between stops in the four sequence types differs. The results in section 4.3.1 concerning the unmasked release percentages of stops and 4.3.2 of ICI duration and distribution patterns were consistent. Consisting of only two stops in the sequence, stops in the C#C sequence exhibited a low release percentage for the SF singleton stop prior to the closure of the HP of the following SI stop and therefore closer gestural coordination, and shorter lag and ICI durations at the word boundary. All homorganic sequences exhibited stop closure overlap in this sequence type. The other C#CC, CC#C, and CC#CC sequence types all exhibited relatively high unmasked stop releases between their stops. In the C#CC sequence, a very weak gestural coordination pattern was found between stops spanning the word boundary, reflected in the 100% release of the SF singleton stop before closure of the HP of SI C1 is reached. Furthermore, long ICI durations where found to occur in this position as a result of the gestures of stops adjacent to the word boundary being further pulled apart. However, stops of the SI cluster of this sequence exhibited closer gestural coordination similar to that exhibited by the stops in the C#C sequence. As a result, stop closure overlap between SI C1 and C2 increased and lag durations were shorter.

Gestural coordination across the word boundary of the CC#C sequence differed from gestural coordination of stops spanning the word boundary of the C#CC sequence. The CC#C sequence exhibited a tight coordination pattern across the word boundary as revealed by the lack of release of SF C2 in homorganic sequences spanning the word boundary and relatively shorter ICIs in tokens where SF C2 was released. However, in terms of the number of stops in both the C#CC and CC#C sequences; both consisting of three stops C1C2C3 and both violating the syllabic template of TLA, the gestural coordination pattern was very similar. In both sequences, the stop gestures of C1 and C2 were not in close coordination and longer ICI lag durations were found between these stops. However, tighter gestural coordination can be found between C2 and C3 of both sequences resulting in more stop closure overlap and shorter lag durations between these stops.

As anticipated, the CC#CC exhibited a complex gestural coordination pattern due to the existence of four stops in the sequence. Stops of the SF cluster exhibited tighter gestural coordination compared to the SF cluster in the CC#C sequence. Similarly, stops of the SI cluster exhibited tighter gestural coordination as revealed by the short lag durations between the HP's of both stops. However, stop gestures spanning the word boundary exhibited the longest lag durations. Here stop gestures are further pulled apart even when homorganic sequences occur across the word boundary. In a nutshell, gestural coordination patterns across the word boundary were weak in both the C#CC and CC#CC sequences. The only exception was the word boundary of the CC#C sequence where shorter lag durations and therefore shorter ICIs occurred in this position as the gestures are in close coordination.

In terms of the unmasked stop release percentages of section 4.3.1, the increase in speech rate did not affect the release patterns exhibited between stops of the four sequence types. However, the increase in speech rate allowed gestures to slide closer to each other resulting in a decrease in lag durations and therefore shorter ICI durations found in section 4.3.2. Despite the tighter coordination of speech gestures as a result of the increase in speech rate, the same stop closure overlap and ICI distribution pattern in the four sequence types occurred in the fast speech rate.

These results also reveal that two distinct types of ICIs emerge. The first is a long ICI occurring where long lag is found between stop gestures that are typical of epenthetic vowel durations that occur in positions where gestural coordination is at its weakest. The second is a short ICI occurring where short lag is found between stop gestures. This type of ICI occurs in positions where closer gestural coordination between stop gestures was exhibited. The second type does not seem to be a true epenthetic vowel but has durations typical to "excrescent" vowels that are a result of the transition process between consonant articulations.

The results in section 4.4 revealed that the order of place of articulation of the stops involved does have an effect on the degree of gestural coordination between stops in the C#C sequence. The results reveal that a significant difference was found between the ICI/OV continuum in the CD and DC contexts. Closer gestural coordination expressed in longer stop closure overlap durations and shorter lag durations can be found between stops in the CD order rather than the DC order of place of articulation. A TT gesture is more closely coordinated with a following TB gesture. The results also reveal that the stop closure overlap durations were not affected by the order of place of articulation in the same manner. Despite closer gestural coordination is exhibited by tokens of the CD order of place of articulation than those of the DC order of place of articulation, this does not suggest that more stop closure overlap is found in tokens of the CD context in comparison to the DC context.

The stop closure overlap durations found in this section are also to be used in inferring overlap durations in the following acoustics data discussed in Chapter five. However, as revealed by the results in section 4.4.3, it is not possible to infer stop closure overlap durations from the duration of stop sequences in the acoustic data. Results show that there is no inverse relation between sequence duration and stop closure overlap durations. The following chapter presents the results of the acoustics data. The same investigations carried out in the EPG data are also conducted in the following chapter. In addition, the nature of the ICIs are investigated further in order to determine whether they are distinct belonging to different types. Furthermore, voice assimilation across the word boundary is investigated only in the acoustics data since the voicing patterns of stops is better understood from the waveform and spectrogram.

Chapter 5 Acoustic results

5.1 Introduction

As for section 4.2 of the EPG data results, section 5.2 presents the timing results of SF and SI singleton stops and clusters in different sequences in order to determine whether an increase in the number of stops in the sequence has an effect on their timing. The HP of SF and SI stops adjacent to the word boundary as highlighted by spectrograms and waveforms are compared in the C#C, CC#C, C#CC, and CC#CC sequences. Similarly, the timing of clusters and any intervening ICI in both SF and SI positions are presented to determine if the behaviour of clusters as a whole is also affected by the increase. These results address research question 1. Section 5.3 mainly deals with patterns of gestural coordination between stops in the four sequence types with emphasis on the word boundary. The results attempt to address research question 2. This includes percentage of stop releases in the four sequence types and resulting lag and ICI duration and distribution patterns. Furthermore, in an attempt to answer research question 4, this section also investigates whether there are two distinct types of ICIs, epenthetic and excrescent, as discussed in the literature review. The nature of the ICIs occurring between stops of the different sequence types are compared in terms of their durations and the effect of voicing of neighbouring stops on their voice qualities. Section 5.4 presents the results of the effect of place order of stops involved on gestural coordination as mentioned in research question 3. This section investigates whether a CD or a DC sequence of consonants spanning the word boundary differ in terms of the degree of gestural coordination, i.e. is gestural coordination affected by the order of place of articulation of the stops involved. Finally, the results of voice assimilation across the word boundary in TLA are presented in section 5.5 which concentrates on addressing research question 5. This section presents results of the direction of voice assimilation and the effect different ICIs have on the process of voice assimilation spread. The results of the direction of voice assimilation and the effect that different ICIs have on the process of voice assimilation spread are revealed.

5.2 The influence of the number of stops in a sequence on the timing of SF and SI stops and clusters

Similar to the EPG data section 4.2, in this section, the timing of stops and stop clusters adjacent to the word boundary, whether in SF or SI position, are presented and compared. The results shed light on the effect an increase in the number of stops in the sequence has on the duration of SF and SI stops adjacent to the word boundary in the four sequence types and therefore aims to answer research question 1.

5.2.1 The influence of the number of stops in sequence on the timing of SF stops

The results of the timing of SF stops /t,d,k,g/ in four positions are presented, two occurring as SF single articulatory gestures in tokens of the **C**#C and **C**#CC sequences, and two occurring as C2 of the SF cluster in tokens of the C**C**#C and C**C**#CC sequences. The duration of the stop HP was identified as the interval between the onset of closure where no acoustic energy was visible on the spectrogram accompanied by an abrupt amplitude drop on the waveform to the release burst.

5.2.1.1 SF alveolar /t/ and /d/

The acoustics data indicate that the mean HP of the single articulatory gesture /t/ was longest when followed by a SI singleton stop in tokens of the **t**#C sequence (Table 5.1. An increase in the number of stops in SI position resulted in a decrease of the mean HP duration of the singleton stop in normal and fast speech rate in tokens of the **t**#CC sequence which is highlighted in figures 5.1 and 5.2. When occurring as C2 of the SF cluster in the C**t**#C sequence, the mean HP duration was 65ms in normal speech rate and 56ms in fast speech rate. Similarly, the increase in the number of stops in SI position resulted in a decrease in the mean HP duration in both speech rates in tokens of the C**t**#CC sequence. As for the effect of speech rate, the HP duration of /t/ decreased as the speech rate increased.

This durational pattern was also exhibited by the individual productions of all speakers except for speakers 2 and 7. In the case of speaker 2, in normal speech rate the mean HP of /t/ remained stable averaging 92ms in tokens of both **t**#C and **t**#CC sequences. As for speaker 7, the mean HP duration of SF C2 in tokens of the C**t**#C sequence averaged 50ms in normal speech rate and increased to 61ms in tokens of the C**t**#CC.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
t#C	ʒit#tal	95.23	30	18.416	71.13	30	11.310
	ʒit#dis	90.33	30	18.615	70.30	30	12.598
	ʒit#kalb	114.50	30	26.115	97.30	30	24.256
	ʒit#giʃ	113.07	30	28.259	85.83	30	19.451
Mean		**103.28**	**120**	**25.345**	**81.14**	**120**	**20.777**
t#CC	bat#tkasir	61.43	30	16.439	48.57	30	11.252
	nat#dkar	90.87	30	14.666	63.83	30	12.972
	nat#kdab	101.20	30	17.050	74.57	30	15.930
	nat#gtal	101.83	30	15.656	73.63	30	18.382
Mean		**88.83**	**120**	**22.811**	**65.15**	**120**	**18.064**
C**t**#C	wagt#tal	69.63	30	12.291	58.50	30	9.598
	wagt#daf	67.23	30	12.552	58.30	30	9.599
	wagt#kif	63.60	30	13.459	54.43	30	12.711
	wagt#giʃ	61.40	30	13.756	56.40	30	9.751
Mean		**65.47**	**120**	**13.254**	**56.91**	**120**	**10.497**
C**t**#CC	wagt#tkasir	51.60	30	12.179	47.57	30	10.874
	wagt#dkar	54.23	30	16.034	49.67	30	14.079
	wagt#ktab	54.57	30	15.400	42.60	30	8.282
	wagt#gdiːm	53.23	30	13.151	43.23	30	9.684
Mean		**53.41**	**120**	**14.145**	**45.77**	**120**	**11.202**

Table 5.1Mean HP duration of SF /t/ at normal and fast speech rate across all speakers

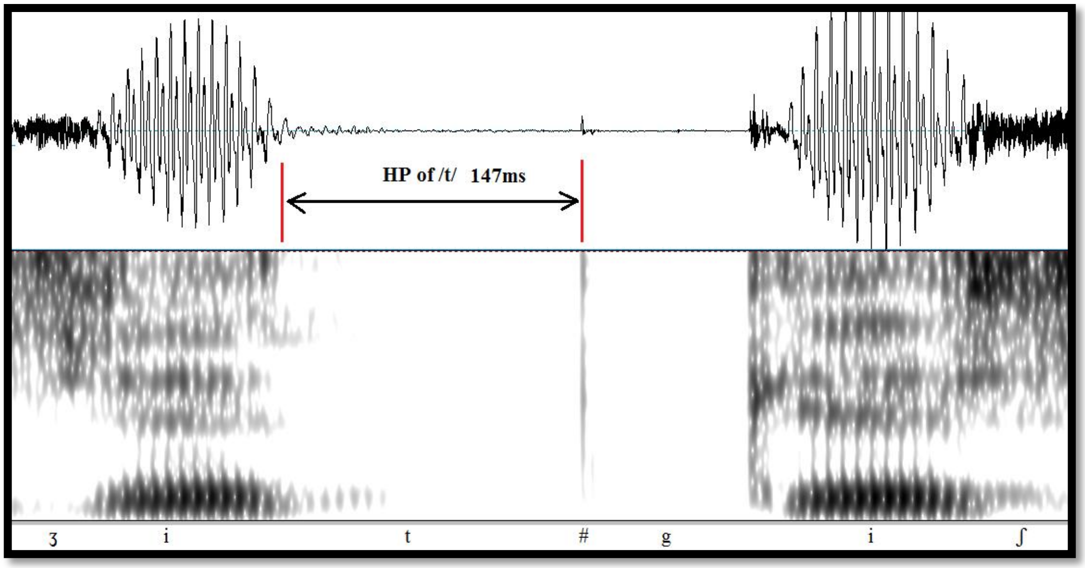


Figure 5.1HP of SF /t/ 147ms in t#C /ʒit#giʃ/ normal speech rate

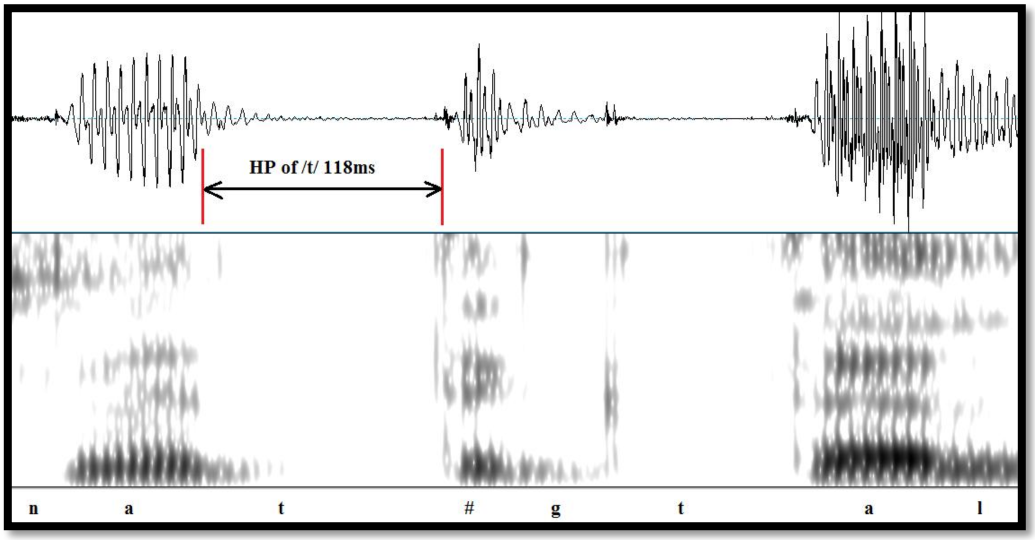


Figure 5.2 HP of SF /t/ 118ms in t#CC /nat#gtal/ normal speech rate

The mean HP duration of voiced SF /d/ was consistent with mean HP duration pattern of voiceless /t/. The duration decreased as the number of stops in the sequence increased as presented in table 5.2. The longest mean HP duration of the single articulatory gesture stop /d/ across all speakers was found in tokens of the **d**#C sequence. This decreased when /d/ was followed by a SI cluster in tokens of the **d**#CC sequence. The same pattern was exhibited when /d/ occurred as C2 of the SF cluster in tokens of the C**d**#C and C**d**#CC sequences. The shortest mean HP duration was in the four-stop C**d**#CC sequence. However, the pattern differed for some individual tokens. For example, the duration of the singleton /d/ in /ʃid#dis/ of the **d**#C sequence remained steady whilst the number of stops in SI position increased in /ʃad#dkar/ of the **d**#CC sequence as opposed to the general mean pattern.

Furthermore, in the case of speaker 5, contrary to the general pattern of a steady decrease in the duration as the number of stops in the sequence increased, in normal speech rate the duration remained steady averaging 84ms in tokens of both the **d**#C and the **d**#CC sequences. This was also the case in the productions of speaker 6.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
d#C	ʃid#tal	104.93	30	19.846	81.63	30	12.764
	ʃid#dis	91.27	30	21.992	71.77	30	10.207
	ʃid#kif	123.27	30	26.608	99.53	30	19.915
	ʃid#giʃ	117.07	30	30.031	92.77	30	38.235
Mean		**109.13**	**120**	**27.519**	**86.42**	**120**	**25.128**
d#CC	ʃad#tkasir	86.40	30	19.220	67.03	30	15.174
	ʃad#dkar	90.83	30	22.656	68.30	30	18.263
	ʃad#ktir	100.60	30	20.017	78.87	30	18.382
	ʃad#gtal	104.53	30	16.167	74.27	30	15.195
Mean		**95.59**	**120**	**20.735**	**72.12**	**120**	**17.287**
C**d**#C	ʔagd#tal	76.30	30	10.433	64.97	30	10.669
	ʔagd#dam	70.00	30	8.052	63.03	30	8.556
	ʔagd#kam	66.43	30	14.899	60.53	30	8.943
	ʔagd#gas	65.17	30	14.669	55.20	30	11.860
Mean		**69.48**	**120**	**12.949**	**60.93**	**120**	**10.625**
C**d**#CC	ʔagd#tkasir	54.03	30	17.196	41.43	30	13.700
	ʔagd#dkar	57.20	30	14.789	48.97	30	9.842
	ʔagd#ktab	49.37	30	10.852	41.57	30	7.514
	ʔagd#gdiːm	49.70	30	13.039	41.53	30	8.589
Mean		**52.58**	**120**	**14.356**	**43.38**	**120**	**10.564**

Table 5.2 Mean HP duration of SF /d/ at normal and fast speech rates across all speakers

5.2.1.2 SF velar /k/ and /g/

The overall mean HP duration of SF /k/ for the production of all speakers was longest when occurring as a singleton stop in tokens of the **k**#C sequence. The mean HP duration decreased when followed by a SI cluster in tokens of the **k**#CC sequence in normal and fast speech rates. This decrease was also exhibited by /k/ when occurring as C2 of the SF cluster in tokens of the C**k**#C sequence. When followed by a SI cluster in tokens of the C**k**#CC sequence, the mean HP duration of SF C2 /k/ decreased. The results in table 5.3 indicate that an increase in the number of stops across the word boundary results in a decrease in the timing pattern of SF /k/. This pattern was consistent for all tokens investigated in normal speech rate. However, in fast speech rate, the decrease was negligible.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
k#C	fak#tal	119.20	30	31.007	84.20	30	25.085
	fak#dam	115.60	30	33.763	81.63	30	23.618
	fak#kif	102.67	30	18.894	77.87	30	15.917
	fak#giʃ	104.57	30	18.455	75.43	30	20.302
Mean		**110.51**	**120**	**27.057**	**79.78**	**120**	**21.517**
k#CC	fak#tkasir	99.07	30	17.691	76.40	30	19.564
	fak#dkar	103.97	30	15.368	78.80	30	16.886
	fak#ktir	94.20	30	15.628	71.10	30	14.184
	fak#gtal	93.97	30	14.646	69.50	30	16.611
Mean		**97.80**	**120**	**16.204**	**73.95**	**120**	**17.132**
C**k**#C	hatk#tal	57.00	30	16.524	51.13	30	14.393
	hatk#dam	57.27	30	12.747	45.00	30	10.386
	hatk#kif	73.23	30	10.731	67.47	30	10.683
	hatk#giʃ	68.77	30	13.776	63.37	30	9.000
Mean		**64.07**	**120**	**15.213**	**56.74**	**120**	**14.390**
C**k**#CC	hatk#tkasir	45.27	30	7.469	48.73	30	13.362
	hatk#dkar	48.83	30	10.544	51.10	30	14.630
	hatk#ktir	61.33	30	20.363	58.17	30	11.980
	hatk#gdi:m	62.20	30	13.700	57.10	30	10.413
Mean		**54.41**	**120**	**15.613**	**53.77**	**120**	**13.150**

Table 5.3 Mean HP duration of SF /k/ at normal and fast speech rates across all speakers

As for variability across speakers, this durational pattern was not consistent for all of them. In the case of the normal speech rate of speaker 2, there was also a slight increase from 90ms in tokens of the **k**#C sequence to 96ms in **k**#CC.

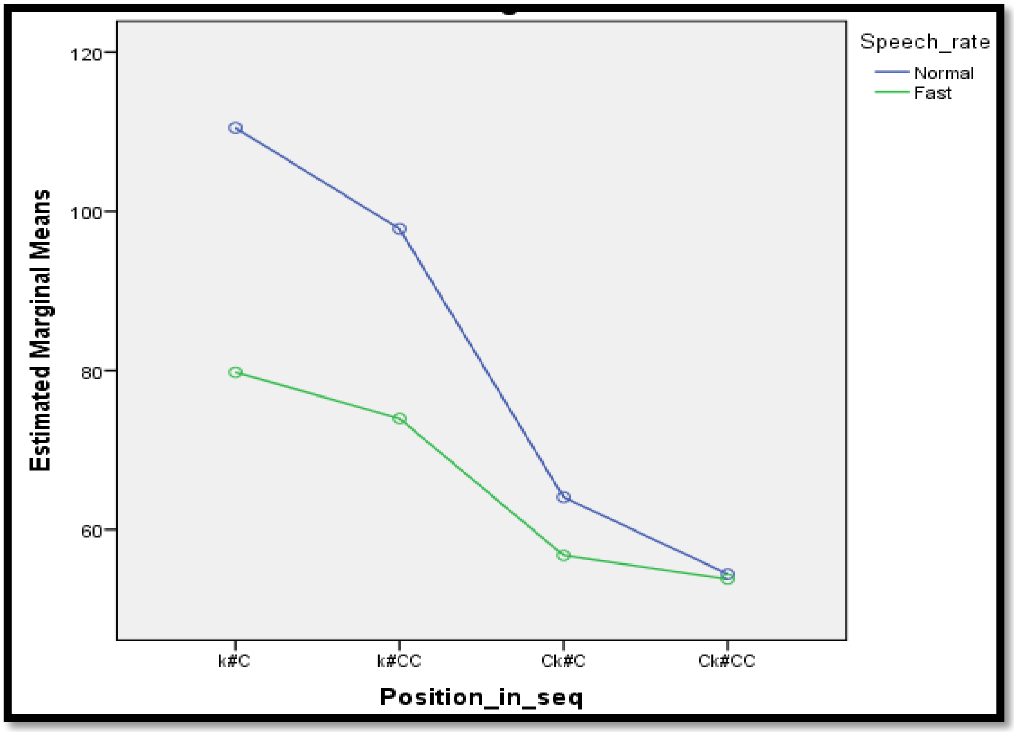


Figure 5.3 Mean HP durations at normal and fast speech rate for SF /k/ in the four sequence positions across all speakers

The mean HP durational pattern of SF voiced velar /g/ was also consistent with the previously investigated syllable-final stops as highlighted in table 5.4. When occurring as a singleton stop in tokens of the **g**#C sequence, the mean HP duration averaged 106ms and decreased to 95ms when followed by a SI cluster in tokens of the **g**#CC sequence. Furthermore, when occurring as SF C2 in tokens of the C**g**#C sequence, in normal speech rate the mean HP averaged 67ms. This also decreased when followed by a SI cluster in tokens of the C**g**#CC sequence where it averaged 55ms. However, in fast speech rate the decrease in mean HP duration averaged only 5ms between tokens of both these sequences.

However, the mean HP of SF /g/ in some tokens was not consistent with this general pattern. In /dag#giʃ/ of the **g**#C sequence and its counterpart /hag#gdi:m/ of the **g**#CC sequence, the mean HP of the SF singleton stop /g/ remained stable in normal speech rate. Similarly, when occurring as SF C2 in /fatg#dam/ of the C**g**#C sequence and counterpart /fatg#dkar/ of the C**g**#CC sequence, in normal speech rate the mean HP of SF C2 remained stable averaging 55ms.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
g#C	dag#tal	113.40	30	25.337	80.70	30	24.554
	dag#dam	108.43	30	27.750	71.63	30	22.530
	dag#kif	105.63	30	17.884	79.50	30	11.907
	dag#giʃ	93.63	30	21.039	71.67	30	16.769
Mean		**106.77**	**120**	**24.120**	**75.87**	**120**	**19.796**
g#CC	ʃag#tkasir	96.70	30	18.063	75.70	30	14.293
	hag#dkar	95.97	30	17.141	78.53	30	17.882
	nag#ktir	94.20	30	17.566	74.50	30	10.285
	hag#gdi:m	93.33	30	24.821	70.40	30	13.130
Mean		**95.05**	**120**	**19.450**	**74.78**	**120**	**14.287**
C**g**#C	fatg#tal	62.53	30	16.899	50.37	30	13.720
	fatg#dam	55.43	30	12.196	44.87	30	8.529
	fatg#kam	77.17	30	16.022	69.00	30	9.255
	fatg#gal	74.53	30	13.940	64.70	30	10.035
Mean		**67.42**	**120**	**17.167**	**57.23**	**120**	**14.437**
C**g**#CC	fatg#tkasir	52.33	30	11.406	49.97	30	8.720
	fatg#dkar	55.10	30	13.914	51.60	30	9.853
	fatg#ktir	60.97	30	16.937	54.00	30	15.320
	fatg#gdi:m	54.97	30	8.624	53.13	30	8.625
Mean		**55.84**	**120**	**13.303**	**52.18**	**120**	**10.950**

Table 5.4 Mean HP duration of SF /g/ at normal and fast speech rates across all speakers

5.2.1.3 Summary

The acoustic data in this section indicates that an increase in the number of stops adjacent to the word boundary in SI position have an effect on the HP of the SF position stops investigated. When occurring as a single articulatory gesture stop in tokens of the **C**#C sequence, the mean HP of the SF stop decreased when followed by a SI cluster in tokens of the **C**#CC sequence. Similarly, when occurring as C2 of the SF cluster in tokens of the C**C**#C sequence, the mean HP decreased as the number of stops increased in SI position in tokens of the C**C**#CC sequence These results are consistent with the EPG results (see section 4.2.). By measuring the HP from the onset of closure to the acoustic release, the duration of the SF single articulatory gesture stop in tokens of the **C**#C sequence was longer than in the **C**#CC sequence where the decrease in the mean HP duration ranged between 11ms-15ms. Furthermore, the SF C2 in tokens of the C**C**#C sequence was longer in duration than SF C2 in C**C**#CC. However, the decrease observed in the latter was shorter ranging between 10ms-12ms.

Furthermore, when followed by a conflicting gesture, the duration of the SF stop in tokens of the **C**#C and **C**#CC sequences is longer than when followed by a homorganic stop. For example, in section 5.2.1.2, the mean HP duration of the SF stop /k/ in /fak#kif/ and /fak#giʃ/ averaged 102ms and 104ms respectively when followed by the same gesture in both examples. However, when followed by a conflicting gesture as in /fak#tal/ and /fak#dam/ where the TB gesture is followed by a TT /t/ and /d/ gesture, the mean HP of SF /k/ averaged 119ms and 115ms respectively. These results are consistent with the results of section 4.2.1 of the EPG data.

In general, the increase in speech rate resulted in the decrease in the duration of the stops investigated in comparison to their durations in normal speech rate. Despite this decrease, the same durational pattern of the SF stops investigated was also found in the fast speech rate. The following section presents the results of the timing of SI stops and the effect the increase of the number of stops in the sequence has on their duration.

5.2.2 The influence of the number of stops in a sequence on the timing of SI stops

The results of the timing of SI stops /t,d,k,g/ in four positions are presented here, two occurring as SI singletons in tokens of the C#**C** and CC#**C** sequences, and two occurring as C1 of the SI cluster in the C#**C**C and CC#**C**C sequences.

5.2.2.1 SI alveolar /t/ and /d/

The results presented in table 5.5 reveal that the longest mean HP duration of SI /t/ occurred in tokens of the C#**t** where it was preceded by a SF singleton stop averaging. The mean HP duration decreased as the number of stops increased in SF position in tokens of the CC#**t** in normal speech and fast speech rates. On the other hand, when comparing the mean HP duration of SI C1 /t/ in tokens of the C#**t**C and CC#**t**C sequences, the mean HP duration did not vary considerably as highlighted by figures 5.4 and 5.5. Despite the increase in the number of stops in SF position, the mean HP duration of SI C1 /t/ in tokens of the C#**t**C sequence remained stable in tokens of the CC#**t**C sequence.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**t**	ʒit#tal	95.23	30	18.416	71.13	30	11.310
	ʃid#tal	105.10	30	19.911	81.53	30	12.741
	fak#tal	85.80	30	14.264	74.13	30	12.045
	dag#tal	87.87	30	12.665	76.60	30	10.702
Mean		**93.50**	**120**	**18.043**	**75.85**	**120**	**12.192**
CC#**t**	wagt#tal	69.47	30	12.528	58.50	30	9.598
	ʔagd#tal	76.30	30	10.433	64.97	30	10.669
	hatk#tal	81.70	30	10.768	69.83	30	12.335
	fatg#tal	79.17	30	13.204	70.63	30	15.531
Mean		**76.66**	**120**	**12.513**	**65.98**	**120**	**13.024**
C#**t**C	bat#tkasir	59.87	30	14.797	48.17	30	12.402
	ʃad#tkasir	62.97	30	31.911	52.60	30	13.182
	fak#tkasir	60.50	30	15.046	52.87	30	12.765
	ʃag#tkasir	58.43	30	10.457	52.17	30	12.006
Mean		**60.44**	**120**	**19.648**	**51.45**	**120**	**12.584**
CC#**t**C	wagt#tkasir	59.47	30	13.331	48.80	30	16.575
	ʔagd#tkasir	63.10	30	17.399	54.07	30	15.863
	hatk#tkasir	57.77	30	15.646	49.70	30	13.814
	fatg#tkasir	56.50	30	10.362	50.87	30	12.787
Mean		**59.21**	**120**	**14.461**	**50.86**	**120**	**14.786**

Table 5.5 Mean HP duration of SI /t/ at normal and fast speech rates across all speakers

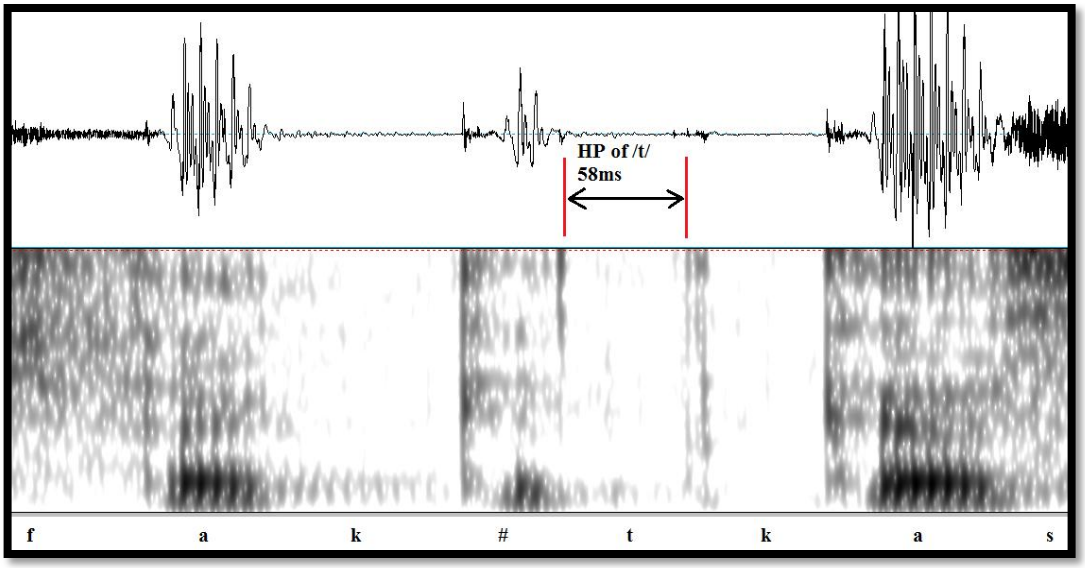


Figure 5.4 HP of SI C1 /t/ preceded by SF single articulatory gesture stop in /fak#tkasir/ of the C#tC sequence at normal speech rate showing a HP of 58ms

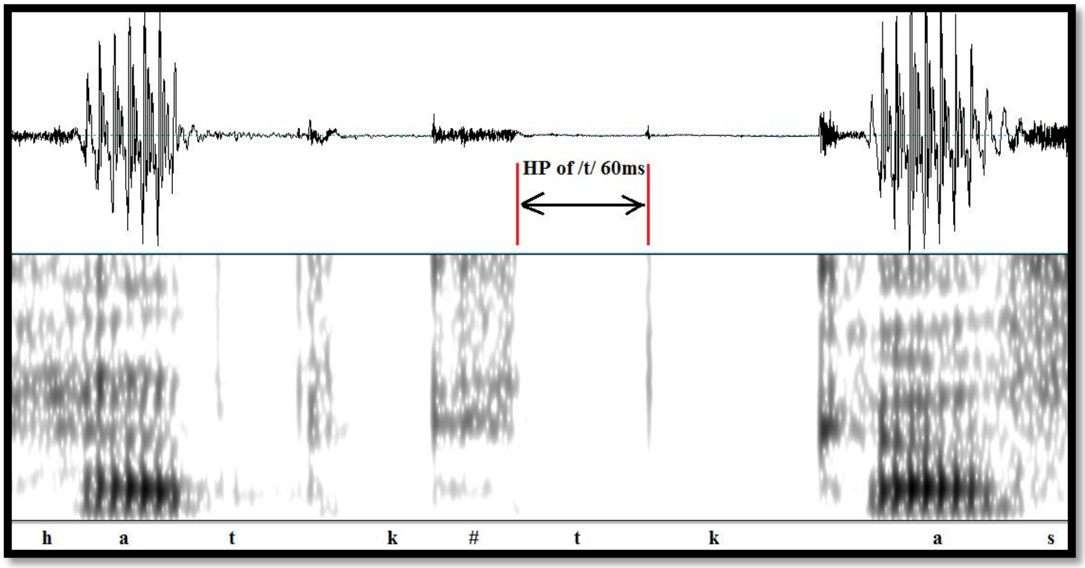


Figure 5.5 HP of SI C1 /t/ preceded by SF cluster in CC#tC token /hatk#tkasir/ at normal speech rate showing a HP of 60ms

This overall pattern was exhibited by all speakers except speaker 2 fast speech rate. In this case, an increase in the mean HP duration of /t/ in tokens of the CC#**t**C in comparison to tokens of the C#**t**C was found as opposed to the general pattern.

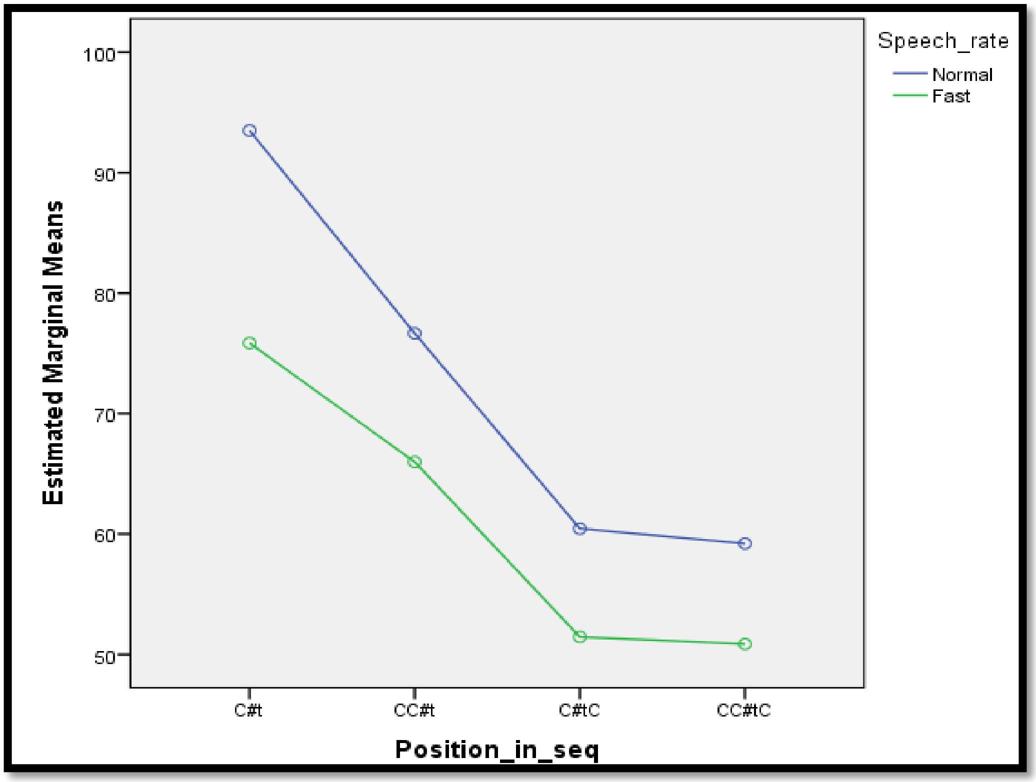


Figure 5.6 Mean HP durations at normal and fast speech rates of SI /t/ in the four sequence positions across all speakers

A similar timing pattern to that of SI /t/ is exhibited by the voiced counterpart /d/. The overall pattern shows that mean HP duration when occurring as a SI singleton was longer in tokens of the C#**d** sequence. As the number of stops increased in SF position, the mean duration decreased in tokens of the CC#**d** sequence in normal and fast speech rate. However, when occurring as SI C1 in tokens of the C#**d**C and CC#**d**C sequences, the mean HP duration of SI C1 /d/ showed little variation (Table 5.6).

However, as opposed to the general pattern, speakers 4, 5, and 8 all exhibited a slight increase in the mean HP duration of the SF C1 in tokens of the CC#**d**C sequence in comparison to the same stop in tokens of the C#**d**C sequence.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
C#**d**	ʒit#dis	90.67	30	18.288	70.23	30	12.626
	ʃid#dis	91.27	30	21.992	71.77	30	10.207
	fak#dam	91.20	30	16.113	78.10	30	13.158
	dag#dam	84.20	30	13.594	72.43	30	13.485
Mean		**89.33**	**120**	**17.793**	**73.13**	**120**	**12.636**
CC#**d**	wagt#daf	67.23	30	12.552	58.30	30	9.599
	ʔagd#dam	70.00	30	8.052	63.03	30	8.556
	hatk#dam	82.33	30	13.379	71.47	30	11.691
	fatg#dam	78.93	30	9.425	69.07	30	9.892
Mean		**74.63**	**120**	**12.581**	**65.47**	**120**	**11.146**
C#**d**C	nat#dkar	72.10	30	16.973	57.87	30	13.201
	ʃad#dkar	62.53	30	17.772	59.10	30	18.443
	fak#dkar	63.23	30	14.668	55.50	30	9.954
	hag#dkar	65.00	30	12.733	56.53	30	14.248
Mean		**65.72**	**120**	**15.926**	**57.25**	**120**	**14.172**
CC#**d**C	wagt#dkar	63.30	30	16.217	56.07	30	12.000
	ʔagd#dkar	64.63	30	11.084	54.80	30	12.928
	hatk#dkar	62.87	30	15.600	52.00	30	12.586
	fatg#dkar	62.93	30	14.300	51.77	30	10.444
Mean		**63.43**	**120**	**14.272**	**53.66**	**120**	**12.016**

Table 5.6 Mean HP duration of SI /d /at normal and fast speech rates across all speakers

5.2.2.2 SI velar /k/ and /g/

Table 5.7 presents the results of the mean HP of SI /k/ in the four sequence positions. The decrease in the mean HP duration can be found in sequences where SI /k/ occurs as a singleton stop. In tokens of the C#**k** sequence, the mean HP duration was longest. This decreased as the number of stops in SF position increased in tokens of the CC#**k** sequence. However, in fast speech rate, this decrease in the mean HP of the SI stop was negligible. Furthermore, when occurring as C1 of the SI cluster in tokens of the C#**k**C sequence, the mean HP duration of SI C1 /k/ did not decrease as the number of stops in SF position increased in tokens of the CC#**k**C sequence. The mean HP duration of SI C1 /k/ in tokens of the C#**k**C did increase when occurring in tokens of the CC#**k**C sequence.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**k**	ʒit#kalb	64.20	30	13.231	51.67	30	10.710
	ʃid#kif	67.77	30	14.253	57.50	30	12.577
	fak#kif	102.53	30	18.686	78.17	30	15.790
	dag#kif	104.63	30	17.884	79.50	30	11.907
Mean		**84.78**	**120**	**24.774**	**66.71**	**120**	**17.736**
CC#**k**	wagt#kif	65.07	30	11.399	54.43	30	11.904
	ʔagd#kam	67.17	30	13.017	58.87	30	9.202
	hatk#kif	73.23	30	10.731	67.47	30	10.683
	fatg#kam	77.17	30	16.022	69.00	30	9.255
Mean		**70.66**	**120**	**13.670**	**62.44**	**120**	**11.851**
C#**k**C	nat#kdab	58.30	30	12.276	49.13	30	7.262
	ʃad#ktir	55.27	30	9.432	47.80	30	12.347
	fak#ktir	55.60	30	9.130	54.17	30	13.465
	nag#ktir	58.67	30	10.643	55.87	30	7.943
Mean		**56.96**	**120**	**10.426**	**51.74**	**120**	**10.998**
CC#**k**C	wagt#ktab	49.43	30	7.370	45.43	30	10.533
	ʔagd#ktab	50.30	30	9.098	45.77	30	13.403
	hatk#ktir	73.33	30	15.210	67.20	30	13.897
	fatg#ktir	61.57	30	15.007	59.20	30	13.867
Mean		**58.66**	**120**	**15.497**	**54.40**	**120**	**15.840**

Table 5.7 Mean HP duration of SI /k/ at normal and fast speech rates across all speakers

Variations between speakers also existed. In normal speech rate, the mean HP duration of /k/ in C#**k**C decreased as opposed to the pattern of increase which occurred in the CC#**k**C sequence. This pattern was exhibited by both the normal and fast speech rates of speakers 6, 8, and 9 and also at fast speech rate of speakers 4, 5, and 9.

The overall mean HP durational pattern for SI /k/ was also exhibited by the voiced counterpart /g/ as highlighted in table 5.8. The mean HP duration of SI /g/ was also longest in tokens of the C#**g** sequence. When preceded by a SF cluster the duration decreased in tokens of the CC#**g**. However, in fast speech rate, a negligible decrease in the mean HP duration of 2ms was found. When preceded by alveolar /t/ and /d/, the mean HP of SI /k/ in tokens of the C#**g** sequence did not vary in duration when occurring in tokens of the CC#**g** sequence. When comparing SI C1 /g/ in tokens of both the C#**g**C and CC#**g**C sequences, the HP in these tokens did not vary and remained stable at both speech rates.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**g**	ʒit#giʃ	67.97	30	12.557	48.57	30	11.676
	ʃid#giʃ	63.47	30	11.016	55.47	30	12.891
	fak#giʃ	104.57	30	18.455	75.43	30	20.302
	dag#giʃ	93.63	30	21.039	71.67	30	16.769
Mean		**82.41**	**120**	**23.610**	**62.78**	**120**	**19.167**
CC#**g**	wagt#giʃ	61.43	30	10.291	54.30	30	11.582
	ʔagd#gas	65.70	30	8.848	56.67	30	12.338
	hatk#giʃ	68.77	30	13.776	64.73	30	10.780
	fatg#gal	74.53	30	13.940	64.70	30	10.035
Mean		**67.61**	**120**	**12.706**	**60.10**	**120**	**12.035**
C#**g**C	nat#gtal	51.33	30	8.248	47.80	30	9.988
	ʃad#gtal	50.03	30	8.931	42.37	30	8.632
	fak#gtal	58.77	30	10.526	52.87	30	10.040
	hag#gdi:m	56.60	30	12.336	54.73	30	10.615
Mean		**54.68**	**120**	**10.542**	**49.44**	**120**	**10.854**
CC#**g**C	wagt#gdi:m	50.47	30	7.413	44.40	30	13.768
	ʔagd#gdi:m	49.67	30	6.728	45.90	30	16.853
	hatk#gdi:m	62.80	30	13.845	61.13	30	12.213
	fatg#gdi:m	57.93	30	8.812	56.87	30	9.153
Mean		**54.97**	**120**	**11.066**	**52.07**	**120**	**14.937**

Table 5.8 Mean HP duration of SI /g/ at normal and fast speech rates across all speakers

Variations between speakers in the mean HP duration of SI /g/ were also found. At normal speech rate, the mean duration of SI /g/ for speakers 1, 4, 6, 8, and 9 decreased slightly in tokens of the CC#**g**C sequence compared to those of the C#**g**C sequence as opposed to the general durational pattern where the mean HP duration remained stable. This decrease was also noted at the fast speech rate for speakers 1, 4, and 10.

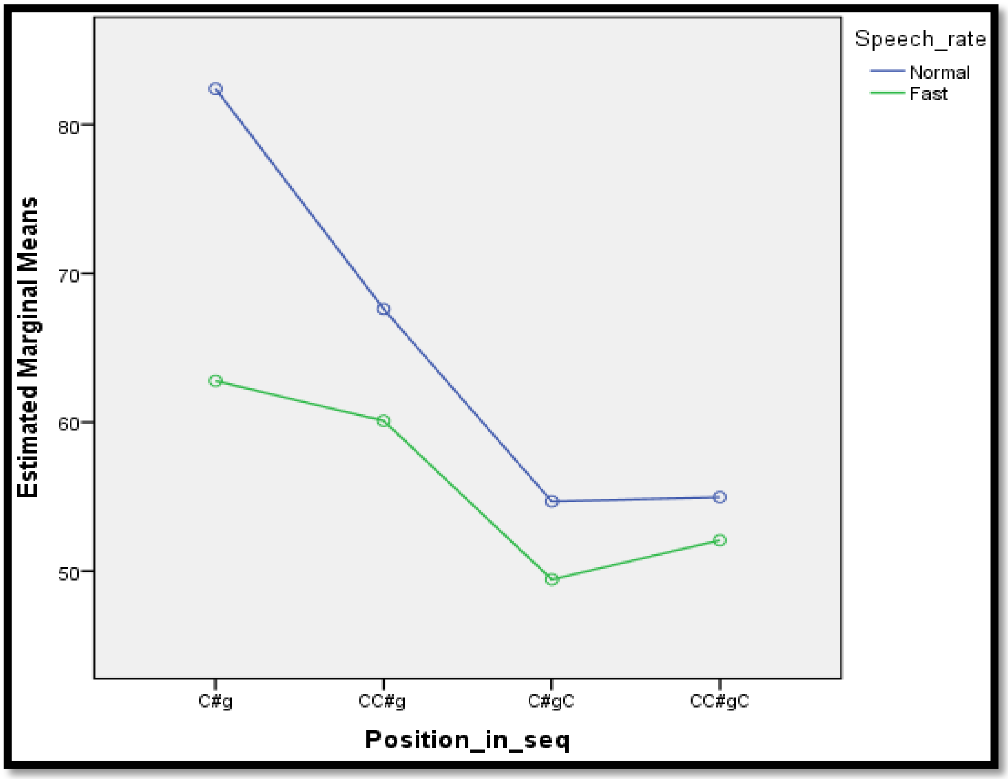


Figure 5.7 Mean durations at normal and fast speech rates for onset position /g/ in the four sequence positions across all speakers

5.2.2.3 Summary

The durational pattern of the SI stop adjacent to the word boundary was not as consistent as the SF stops described in section 5.2.1. In the latter, a decrease in the mean HP duration was found as the number of stops on the other side of the word boundary increased for all the four sequence types. These results are in line with the EPG data results (see section 4.2.2). A decrease in the mean HP duration was found when comparing the HP duration of the SI stop in tokens of the C#**C** sequence to the HP duration of the SI stop in tokens of the CC#**C** sequence resulting from an increase in the number of stops in SF position. The mean decrease in the HP ranged from 14-17ms. However, the decrease in duration of C1 of the SI stop in C#**C**C was not significant when the number of stops increased in SF position in the CC#**C**C sequence and remained stable in both speech rates. In most tokens investigated, the mean HP duration of SI C1 remained stable as highlighted in figures 5.4 and 5.5. In contrast, in previous investigations of SF stops (sections 4.2. and 5.2.), SF C2 stops in tokens of the C**C**#C sequence exhibited a decrease when followed by a SI cluster in the C**C**#CC sequence. The difference in timing of SF and SI stops indicates that SI stops are more stable than SF stops as a result of an increase in the number of stops in the sequence.

Furthermore, there was an overall decrease in the mean HP duration of all stops investigated at fast speech rate when compared to the mean HP durations of the same tokens at normal speech rate. This highlights the fact that speech rate is also a factor that influences the duration of stops in sequences. The following section investigates the effect that an increase in the number of stops on the adjacent side of the word boundary has on the timing of SF and SI stop clusters.

5.2.3 The influence of the number of stops on the timing of SF stop clusters

This section presents results of the mean duration of SF cluster in tokens of the **CC**#C and **CC**#CC sequences. These results shed light on the effect that the number of stops in SI position have on the timing of SF clusters.

5.2.3.1 SF dorsal-coronal /gt/ and /gd/ clusters

Table 5.9 presents the results of the mean duration of the SF cluster /gt/. The pattern indicates a decrease in the mean duration of the SF cluster as the number of stops in the SI position increase. In tokens of the **gt**#C sequence, the mean duration of the SF /gt/ cluster was longest in normal and fast speech rate. The increase in the number of stops in SI position in tokens of the **gt**#CC sequence resulted in a decrease in the duration in both normal and fast speech rate. The decrease in duration was shorter in fast speech rate as a result of the increase in speech rate which affected the duration of all segments of the cluster.

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
gt#C	wagt#tal	177.77	30	16.972	135.90	30	12.494
	wagt#daf	175.87	30	16.313	136.47	30	12.990
	wagt#kif	165.60	30	20.611	128.60	30	18.854
	wagt#giʃ	166.57	30	22.797	129.27	30	14.326
Mean		**171.45**	**120**	**19.871**	**132.56**	**120**	**15.138**
gt#CC	wagt#tkasir	117.77	30	20.873	104.10	30	16.597
	wagt#dkar	126.27	30	23.462	112.37	30	27.641
	wagt#ktab	123.63	30	23.799	103.33	30	9.746
	wagt#gdi:m	122.07	30	18.038	104.03	30	12.207
Mean		**122.43**	**120**	**21.616**	**105.96**	**120**	**18.074**

Table 5.9 Mean duration of SF /gt/ cluster at normal and fast speech rates

The same timing pattern was found in the /gd/ SF cluster presented in table 5.10. Speech rate also resulted in an overall decrease in the SF cluster duration. At fast speech rate, the duration of the SF /gd/ cluster decreased in comparison to the normal speech rate.

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
gd#C	ʔagd#tal	184.63	30	18.416	150.50	30	18.239
	ʔagd#dam	180.30	30	18.471	145.73	30	15.728
	ʔagd#kam	170.47	30	28.987	140.30	30	18.894
	ʔagd#gas	166.87	30	25.303	130.33	30	16.050
Mean		**175.57**	**120**	**24.054**	**141.72**	**120**	**18.650**
gd#CC	ʔagd#tkasir	126.80	30	21.753	100.27	30	19.467
	ʔagd#dkar	132.93	30	20.272	108.20	30	18.933
	ʔagd#ktab	119.67	30	18.945	98.83	30	14.907
	ʔagd#gdi:m	120.93	30	19.884	97.47	30	10.757
Mean		**125.08**	**120**	**20.671**	**101.19**	**120**	**16.720**

Table 5.10 Mean duration of SF /gd/ cluster at normal and fast speech rates

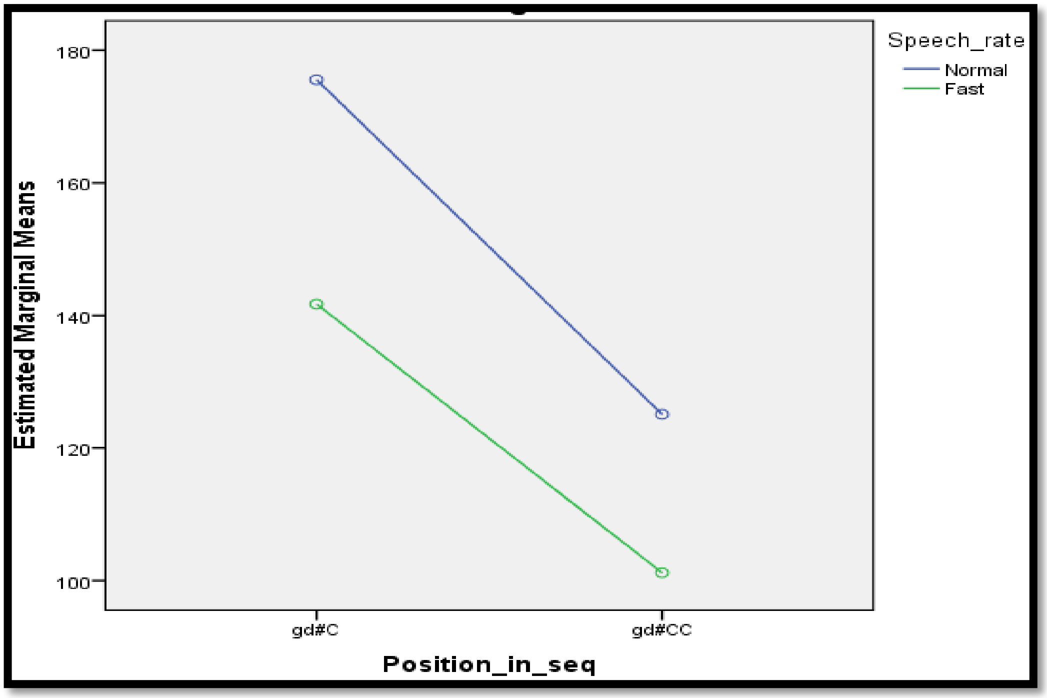


Figure 5.8 Mean durations at normal and fast speech rates for SF /gd/ cluster in both positions across all speakers

5.2.3.2 SF coronal-dorsal /tk/ and /tg/ clusters

Results of table 5.11 indicate that the mean duration of SF /tk/ cluster in normal speech rate is shorter in tokens of the **tk**#CC sequence compared to the same SF cluster in tokens of the **tk**#C sequence. This is also the case at fast speech rate but with a smaller decrease of 18ms. However, a slight increase in the duration of the SF cluster in the **tk**#CC sequence was found in the productions of speaker 7 in comparison with the mean SF cluster duration in the tokens of the **tk**#C This increase was also found in the fast speech rate of speakers 3 and 7.

Sequence	Token	Normal			Fast		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
tk#C	hatk#tal	156.70	30	23.800	129.50	30	22.735
	hatk#dam	158.20	30	27.094	120.53	30	18.737
	hatk#kif	186.17	30	19.336	154.27	30	14.678
	hatk#giʃ	180.97	30	17.596	150.93	30	10.818
Mean		**170.51**	**120**	**25.674**	**138.81**	**120**	**22.269**
tk#CC	hatk#tkasir	125.10	30	17.247	115.63	30	18.635
	hatk#dkar	129.57	30	16.218	119.70	30	22.178
	hatk#ktir	134.83	30	27.959	122.77	30	14.552
	hatk#gdi:m	135.57	30	16.456	122.40	30	16.635
Mean		**131.27**	**120**	**20.280**	**120.13**	**120**	**18.214**

Table 5.11 Mean duration of SF /tk/ cluster at normal and fast speech rates

The SF cluster /tg/ also exhibited the same durational pattern in the **tg**#C and the **tg**#CC sequences. The total mean SF cluster duration at both speech rates was longer in the **tg**#C sequence in comparison with the **tg**#CC sequence (table 5.12).

Sequence	Token	Normal			Fast		
		Mean (ms)	N	Std. Dev.	Mean (ms)	N	Std. Dev.
tg#C	fa**tg**#tal	165.10	30	27.158	126.13	30	17.706
	fa**tg**#dam	157.27	30	23.818	121.40	30	17.340
	fa**tg**#kam	190.47	30	25.667	157.50	30	14.073
	fa**tg**#gal	185.20	30	20.128	154.67	30	15.916
Mean		**174.51**	**120**	**27.705**	**139.92**	**120**	**22.952**
tg#CC	fa**tg**#tkasir	122.03	30	20.833	113.47	30	16.782
	fa**tg**#dkar	129.47	30	21.697	118.43	30	15.806
	fa**tg**#ktir	130.37	30	25.022	120.80	30	25.531
	fa**tg**#gdi:m	126.83	30	13.049	115.77	30	17.226
Mean		**127.17**	**120**	**20.619**	**117.12**	**120**	**19.193**

Table 5.12 Mean duration of SF /tg/ cluster at normal and fast speech rates

5.2.3.3 Summary

The results indicate that all SF clusters of the **CC**#C sequence are characterized by a decrease in the duration when occurring in the **CC**#CC sequence. These results are consistent with the results of the EPG data (see section 4.2.3). Results in section 5.2 indicate that SF C2 in the C**C**#CC sequence is shorter in duration than the SF single articulatory gesture stop in **C**#CC due to the pseudo geminate nature of the latter. This was also found in the EPG data section 4.2. However, the mean decrease in duration of the SF stop (see sections 4.2.1 and 5.2.1) was less than the decrease in the duration of the whole SF cluster found in the acoustics data. The decrease in duration of SF C2 in C**C**#C compared to SF C2 in C**C**#CC ranged from 12ms to 17ms in normal speech rate. On the other hand, results of this section indicate that the decrease in the mean duration of the SF cluster in the **CC**#CC sequence compared to the **CC**#C sequence ranged from 39ms to 50ms. This shows that the decrease in duration of the SF cluster is not just a result of the decrease in the duration of SF C2 but also as a result of the different ICI durations occurring between C1 and C2 of the SF cluster in the **CC**#C and **CC**#CC sequences. As previously mentioned in section 4.4.3, this can be attributed to the lag durations occurring between C1 and C2 of the SF clusters. The results of sections 4.3.2.3 and 4.3.2.4 indicate that gestural coordination between C1 and C2 of the SF cluster in **CC**#C and **CC**#CC sequences differ. Longer lag durations and therefore longer ICI durations are found between stops of the SF cluster of the **CC**#C sequence compared to the SF cluster in the **CC**#CC sequence resulting in longer SF clusters in the former. As a result, the increase in gestural coordination in addition to the decrease in the HP of SF C2 resulted in a decrease in the duration of the SF cluster in **CC**#CC compared to the SF cluster in **CC**#C. This is further investigated in section 5.3 of this chapter to confirm that the difference in gestural coordination pattern between stops of the SF cluster in the **CC**#C and **CC**#CC sequences of the acoustics data exhibit the same coordination pattern as found in the EPG data in sections 4.3.2.3 and 4.3.2.4. The next section investigates the timing of SI clusters in both C#**CC** and CC#**CC** sequences.

5.2.4 The influence of the number of stops on the timing of SI stop clusters

This section presents the results of the mean duration of SI cluster in tokens of the C#**CC** and CC#**CC** sequences. These results shed light on the effect that the number of stops in SF position has on the timing of SI clusters.

5.2.4.1 SI coronal-dorsal /tk/ and /dk/ clusters

Table 5.13 presents the results of the mean SI cluster /tk/ durations in tokens of the C#**tk** and CC#**tk** sequences. These results show that the timing pattern of SI clusters is different from that of the SF clusters described in sections 4.2.3 of the EPG chapter and section 5.2.3 of this chapter. The mean duration of the SI cluster in both sequences remains stable at 131ms in both sequences. At fast speech rate, there was an increase of 5ms.

The same durational pattern is exhibited by the syllable-initial /dk/ cluster. The total mean duration in normal speech rate averaged 142ms in tokens of the C#**dk** sequence and 141ms when preceded by a coda cluster in tokens of the CC#**dk** sequence (table 5.14).

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**tk**	bat#**tk**asir	131.03	30	19.990	106.67	30	16.221
	ʃad#**tk**asir	138.83	30	26.878	110.80	30	19.937
	fak#**tk**asir	128.83	30	15.302	113.00	30	17.597
	ʃag#**tk**asir	126.53	30	15.290	114.23	30	14.619
Mean		**131.31**	**120**	**20.225**	**111.18**	**120**	**17.230**
CC#**tk**	wagt#**tk**asir	125.57	30	16.075	113.60	30	19.329
	ʔagd#**tk**asir	134.03	30	18.524	117.47	30	18.552
	hatk#**tk**asir	133.83	30	20.427	116.70	30	19.148
	fatg#**tk**asir	130.50	30	15.092	118.13	30	12.835
Mean		**131.15**	**120**	**17.766**	**116.47**	**120**	**17.535**

Table 5.13 Mean duration of SI /tk/ cluster at normal and fast speech rates

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**dk**	nat#**dk**ar	146.63	30	20.727	125.23	30	18.420
	ʃad#**dk**ar	141.90	30	23.127	128.53	30	24.150
	fak#**dk**ar	138.40	30	20.549	123.87	30	15.024
	hag#**dk**ar	141.43	30	16.604	122.70	30	19.554
Mean		**142.09**	**120**	**20.344**	**125.08**	**120**	**19.437**
CC#**dk**	wagt#**dk**ar	139.17	30	19.825	126.90	30	16.476
	ʔagd#**dk**ar	143.83	30	18.890	128.30	30	15.888
	hatk#**dk**ar	143.70	30	21.602	126.27	30	17.463
	fatg#**dk**ar	140.73	30	17.078	125.27	30	12.253
Mean		**141.86**	**120**	**19.275**	**126.68**	**120**	**15.485**

Table 5.14 Mean duration of SI /dk/ cluster at normal and fast speech rates

Variation between the average means for speakers was found in the production of this syllable-initial cluster. At normal speech rate for speakers 1, 5, and 7, there was an increase in the mean duration of /dk/ in tokens of the CC#**dk** sequence compared to those for the C#**dk** sequence as opposed to the general pattern where there was a decrease in the mean duration of this cluster when preceded by a SF cluster. At fast speech rate, the mean duration of SI /dk/ cluster for speakers 3, 4, 8, and 9 showed a slight decrease in their mean duration in tokens of the CC#**dk** sequence compared to those of the C#**dk** sequence.

5.2.4.2 SI dorsal-coronal /kt/ and /gd/ clusters

As with the previous SI clusters investigated, the durational pattern exhibited by SI /tk/ was consistent with the previous SI clusters. In normal speech rate, the mean duration of SI /tk/ averaged 145ms in tokens of the C#**tk** sequence and 147ms in those of the CC#**tk** sequence showing a negligible increase of 2ms. At fast speech rate, the mean duration of SI /tk/ cluster remained stable in tokens of both these sequences (table 5.15).

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**kt**	ʃad#**kt**ir	144.33	30	14.325	126.00	30	19.761
	fak#**kt**ir	145.07	30	18.895	135.67	30	23.182
	nag#**kt**ir	145.27	30	16.278	137.30	30	13.634
Mean		**144.89**	**90**	**16.422**	**132.99**	**90**	**19.699**
CC#**kt**	wagt#**kt**ab	139.80	30	16.437	123.10	30	12.425
	ʔagd#**kt**ab	141.53	30	13.263	124.33	30	23.314
	hatk#**kt**ir	152.60	30	25.129	146.67	30	20.795
	fatg#**kt**ir	146.73	30	17.767	136.80	30	20.619
Mean		**147.67**	**120**	**20.519**	**132.72**	**120**	**21.757**

Table 5.15 Mean duration of SI /kt/ cluster at normal and fast speech rates

In the case of speakers 4, 5, 6, 8, and 9, there was a slight decrease in the mean duration of /kt/ in tokens of the CC#**kt** sequence ranging from 2ms to 11ms compared to the mean in tokens of the C#kt sequence. As for speakers 2, 3, 7, and 10, an increase was seen in the mean durations of /kt/ in tokens of the CC#**kt** sequence compared to the C#**kt** sequence. This variation ranged from 7ms to 30ms.

Furthermore, the mean duration of the SI /gd/ also exhibited the same pattern as the number of stops increased in SF position preceding the word boundary. The mean duration was not affected in tokens of both the C#**gd** and CC#**gd** sequences (table 5.16).

Sequence	**Token**	**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
C#**gd**	hag#**gd**iːm	144.33	30	14.325	126.00	30	19.761
Mean		**144.89**	**90**	**16.422**	**132.99**	**90**	**19.699**
CC#**gd**	wagt#**gd**iːm	139.80	30	16.437	123.10	30	12.425
	ʔagd#**gd**iːm	141.53	30	13.263	124.33	30	23.314
	hatk#**gd**iːm	162.60	30	25.129	146.67	30	20.795
	fatg#**gd**iːm	146.73	30	17.767	136.80	30	20.619
Mean		**147.67**	**120**	**20.519**	**132.72**	**120**	**21.757**

Table 5.16 Mean duration of SI /gd/ cluster at normal and fast speech rates

Variations between speakers were found in the mean durational pattern of SI /gd/ were found. In normal speech rate, as opposed to the general durational pattern showing a decrease in the mean duration of SI /gd/ in the CC#**gd** compared to that of C#**gd** sequence, the durational pattern of the mean for speakers 1, 2, and 7 showed an increase in the mean duration of SI /gd/ when occurring in tokens of the CC#**gd** sequence. This increase ranged between 10ms-21ms. In fast speech rate, speakers 3, 5, and 7 also showed a similar increase in the mean duration of SI /gd/ when occurring in tokens of the CC#**gd** sequence compared to those of the C#**gd** sequence.

5.2.4.3 Summary

Results of the timing of SI clusters in the two sequence types indicate that SI clusters are not greatly affected by the number of stops in the sequence. These results are consistent with the results for the SI clusters in the EPG data (see section 4.2.4). Whilst the results for SF clusters (sections 4.2.3 and 5.2.3) showed a considerable decrease in their mean duration in the **CC**#C sequence compared to the SF cluster in the **CC**#CC sequence, ranging between 39ms and 50ms, SI clusters exhibited more stability in their duration. The overall pattern indicates that the mean duration of clusters in SI position did not exhibit a sharp decrease when preceded by a SF cluster. The mean duration of the SI cluster in the C#**CC** sequence did not decrease when occurring in the CC#**CC** sequence due to the increase in the number of stops in the SF position.

5.3 Intergestural timing and patterns of gestural coordination in stop sequences

This section presents the results of intergestural timing and patterns of gestural coordination in stop sequences with the aim of addressing research question 2. Acoustic behaviour of stops is expressed in terms of the percentage of stop releases in the four sequence types in addition to lag durations occurring between the HP's of two adjacent stops and patterns of ICI distribution. This section concludes by presenting the results of the effect of place order of stops involved on gestural coordination as mentioned in research question 3.

An increase in the release of C1 between any two adjacent stop gestures C1C2 reveals a lack of stop closure overlap. The resulting presence of an ICI as highlighted by the acoustic release on the spectrogram and waveform suggests less gestural coordination and open transition between gestures of adjacent stops whereas the absence of an acoustic release in cases when the release of one stop gesture is masked by the HP of C2 indicates closer gestural coordination. The degree of gestural coordination is measured in terms of the temporal lag between release of C1 and C2 closure, i.e. the ICI duration. An acoustic release in the acoustic analysis is identified by the vertical spike on the waveform after a period of silence or the sudden increase in high frequency acoustic energy on the spectrogram as a result of the sudden release of the articulators.

5.3.1 Release percentages and gestural coordination

This section presents the results of the release of the HP of a C1 stop of a C1C2 sequence before the formation of the HP of C2 and corresponds to section 4.3 of the EPG data.

5.3.1.1 Release percentage of SF stop in C#C sequence

At normal speech rate, stop closure overlap occurred in 50% of the tokens. This remained steady with a slight decrease in fast speech rate as presented in table 5.17. Being composed of only two stops, a high percentage of stop closure overlap was found across the word boundary in homorganic tokens of this sequence. All of the tokens consisting of homorganic stops spanning the word boundary whether coronal#coronal or dorsal#dorsal exhibited stop closure overlap. These can be found in the homorganic sequence tokens /ʒit#tal/, /ʒit#dis/, /ʃid#tal/, /ʃid#dis/, /fak#kif/, /fak#giʃ/, /dag#kif/, and /dag#giʃ/. In these sequences, the HP’s of the gestures can be said to be coordinated in that the release of C1 is masked by the closure of C2 of the sequence.

As anticipated, the SF single articulatory gesture stop was always released before closure of the SI stop is attained in heterorganic sequences. In these tokens, stop gestures are not in close coordination resulting in the absence of any stop closure overlap period.

The same pattern is also found in fast speech rate. The increase in speech rate did not result in a significant decrease in the percentage of stop closure overlap across the word boundary. No speaker variability was found. The same pattern was exhibited by all 10 speakers.

	Normal			Fast		
Token	**# rls.**	**% rls.**	**N**	**# rls.**	**% rls.**	**N**
ʒit#tal	0	-	30	0	-	30
ʒit#dis	0	-	30	0	-	30
ʒit#kalb	30	100	30	30	100	30
ʒit#giʃ	29	96	30	30	100	30
ʃid#tal	0	-	30	0	-	30
ʃid#dis	0	-	30	0	-	30
ʃid#kif	30	100	30	30	100	30
ʃid#giʃ	29	96	30	26	96	30
fak#tal	30	100	30	29	96	30
fak#dam	29	96	30	30	100	30
fak#kif	0	-	30	0	-	30
fak#giʃ	0	-	30	0	-	30
dag#tal	30	100	30	29	96	30
dag#dam	30	100	30	29	96	30
dag#kif	0	-	30	0	-	30
dag#giʃ	0	-	30	0	-	30
Mean	**237**	**49.4%**	**480**	**233**	**48.5%**	**480**

Table 5.17 Number of unmasked releases across word boundary and percentages in C#C sequence tokens at normal and fast speech rates

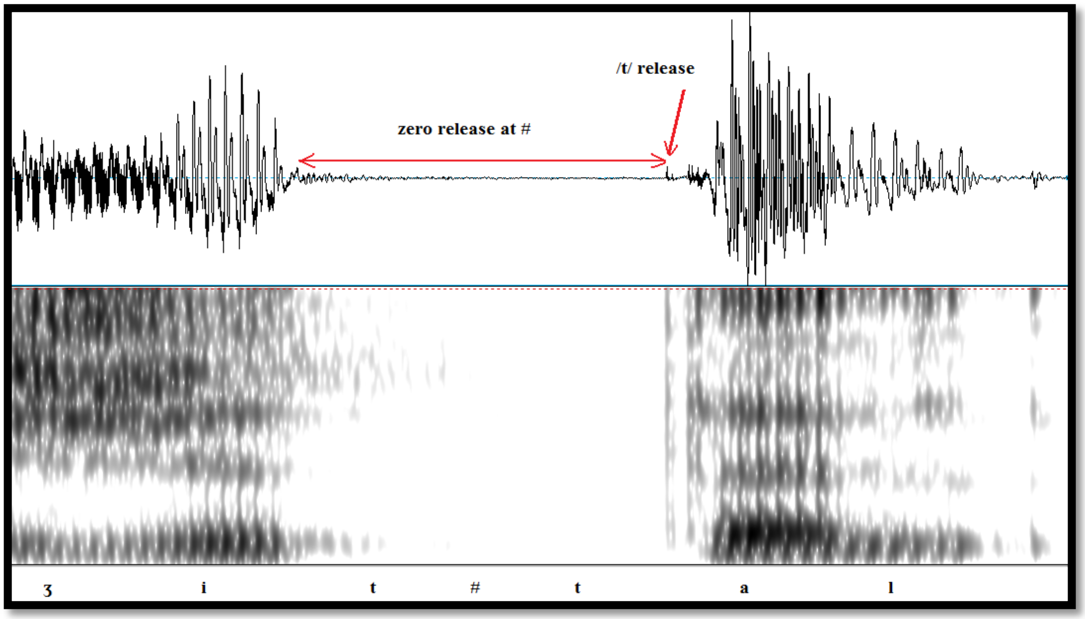


Figure 5.9 Absence of acoustic release at word boundary in C#C homorganic sequence /ʒit#tal/ normal speech rate

5.3.1.2 Release percentage of stops in C#CC sequence

The unmasked release of the SF single articulatory gesture stop preceding the word boundary increased in the C#CC sequence as seen in table 5.18. This three-stop sequence violates the total number of stops permitted by the syllabic template of TLA and stop gestures are not closely coordinated resulting in an increase in the unmasked release of the SF stop.

	Normal					**Fast**				
Token	**# rls**	**% rls.**	**SI rls**	**% rls.**	**N**	**# rls.**	**% rls.**	**SI rls.**	**% rls.**	**N**
bat#tkasir	15	50	30	100	30	4	13	30	100	30
nat#dkar	21	70	30	100	30	14	46	30	100	30
nat#kdab	30	100	30	100	30	30	100	30	100	30
nat#gtal	30	100	30	100	30	30	100	28	93	30
ʃad#tkasir	21	70	30	100	30	18	60	30	100	30
ʃad#dkar	22	73	30	100	30	15	50	30	100	30
ʃad#ktir	30	100	30	100	30	30	100	30	100	30
ʃad#gtal	30	100	30	100	30	30	100	29	96	30
fak#tkasir	30	100	30	100	30	30	100	29	96	30
fak#dkar	30	100	30	100	30	30	100	30	100	30
fak#ktir	30	100	30	100	30	22	73	29	96	30
fak#gtal	30	100	30	100	30	23	76	30	100	30
ʃag#tkasir	30	100	30	100	30	30	100	30	100	30
hag#dkar	30	100	30	100	30	30	100	29	96	30
nag#ktir	30	100	30	100	30	27	90	30	100	30
hag#gdi:m	30	100	30	100	30	26	96	30	100	30
Mean	**439**	**91%**	**480**	**100%**	**480**	**389**	**81%**	**474**	**98%**	**480**

Table 5.18 Number of unmasked releases across word boundary and in SI cluster of C#CC sequence tokens at normal and fast speech rates

The acoustic data indicates that stop gestures in this position are not synchronised resulting in a high percentage of unmasked stop closures averaging 91% in normal speech rate. At this speech rate, the only tokens that did exhibit masked SF stop releases are the coronal#coronal homorganic sequences. Dorsal#dorsal homorganic sequences did not exhibit any stop closure overlap as highlighted in figure 5.10.

The increase in speech rate led to a slight decrease in the unmasked release percentage of the SF stop, suggesting a slight increase in gestural coordination in fast speech rate. This occurred in the coronal#coronal homorganic sequences across the word boundary. However, stop closure overlap was also found in homorganic sequences of the dorsal#dorsal type in fast speech rate. In /fak#ktir/, /fak#gtal/, /nag#ktir/, and /hag#gdi:m/, the HP of the velar gesture was not released across the word boundary in 8, 7, 3, and 4 repetitions respectively.

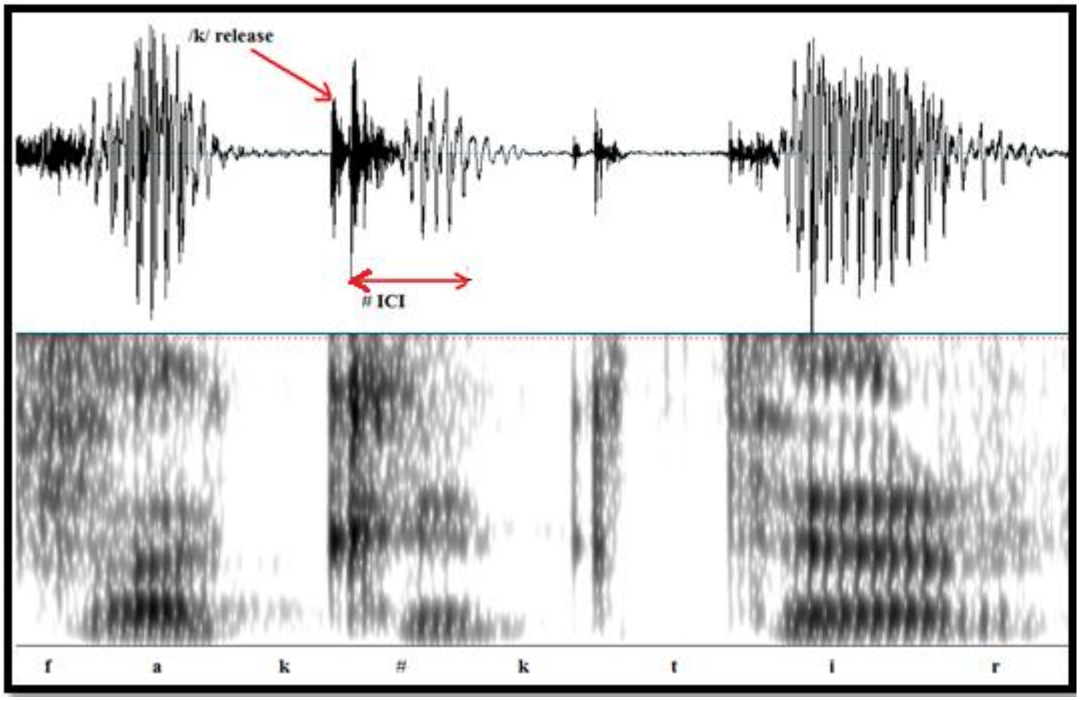


Figure 5.10 Unmasked stop release across word boundary in C#CC sequence /fak#ktir/ at normal speech rate

Furthermore, the results reveal that gestural coordination between stop gestures of the SI cluster of this C#CC sequence is characterised by a high percentage of unmasked SI C1 releases. In normal speech rate, the mean percentage release of SI C1 was 100% and remained almost stable in fast speech rate. Only 6 out of a total of 480 repetitions exhibited stop closure overlap between gestures of the SI cluster in fast speech rate. It is also worth mentioning that all SI clusters consist of heterorganic stops.

This general pattern was consistent in the productions of all participants except speaker 7 who exhibited a slight increase in stop closure overlap across the word boundary where the release percentage was 65% across the word boundary in normal speech rate.

5.3.1.3 Release percentage of stops in CC#C sequence

A different stop closure overlap pattern was found in this three-stop sequence (Table 5.19). In the SF cluster, gestural coordination between stops of the cluster is characterised by the lack of gestural coordination with unmasked releases of SF C1 occurring in all tokens. This is also the case in fast speech rate. Stops in the SF cluster are not closely coordinated. However, a decrease in the percentage of unmasked stop closure releases can be seen across the word boundary. The percentage of unmasked SF C2 release in normal speech rate was 49% in normal speech rate and 48% in fast speech rate. Stop closure overlap between SF C2 and SI C1 occurred in all homorganic sequences spanning the word boundary in both speech rates (figure 5.11). This pattern is very similar to that found across the word boundary in the C#C sequence (section 5.3.1.1) and also in the EPG results investigating the same CC#C sequence (section 4.3.1.3). Like the former sequence, stop closure overlap occurred in both coronal#coronal and dorsal#dorsal homorganic sequences across the word boundary at both speech rates. The only heterorganic token exhibiting stop closure overlap across the word boundary was found in one repetition of /wagt#giʃ/ in normal speech rate. In fast speech rate, 4 repetitions exhibited stop closure overlap across the word boundary in /ʕagd#gas/ and 1 repetition in /hatk#tal/. Unmasked stop releases across the word boundary occurred in all remaining heterorganic sequences (figure 5.12).

	Normal					**Fast**				
Token	**SF rls.**	**% rls.**	**# rls.**	**% rls.**	**N**	**SF rls.**	**% rls.**	**# rls.**	**% rls.**	**N**
wagt#tal	30	100	0	-	30	30	100	0	-	30
wagt#daf	30	100	0	-	30	30	100	0	-	30
wagt#kif	30	100	30	100	30	30	100	30	100	30
wagt#giʃ	30	100	29	96	30	30	100	30	100	30
ʔagd#tal	30	100	0	-	30	30	100	0	-	30
ʔagd#dam	30	100	0	-	30	30	100	0	-	30
ʔagd#kam	30	100	30	100	30	30	100	30	100	30
ʔagd#gas	30	100	30	100	30	30	100	26	86	30
hatk#tal	30	100	30	100	30	30	100	29	96	30
hatk#dam	30	100	30	100	30	30	100	30	100	30
hatk#kif	30	100	0	-	30	30	100	0	-	30
hatk#giʃ	30	100	0	-	30	30	100	0	-	30
fatg#tal	30	100	30	100	30	30	100	29	96	30
fatg#dam	30	100	30	100	30	30	100	30	100	30
fatg#kam	30	100	0	-	30	30	100	0	-	30
fatg#gal	30	100	0	-	30	30	100	0	-	30
Mean	**480**	**100%**	**239**	**49%**	**480**	**480**	**100%**	**234**	**48%**	**480**

Table 5.19 Number of unmasked releases in SF cluster and across word boundary of CC#C sequence tokens at normal and fast speech rate

At normal speech rate, no speaker variability was exhibited in the individual productions of all 10 speakers. However, at fast speech rate, speakers 1, 2, and 3, exhibited a slight decrease in the percentage of unmasked releases across the word boundary resulting in a slightly closer gestural coordination pattern between stops spanning the word boundary than was the case for the other speakers.

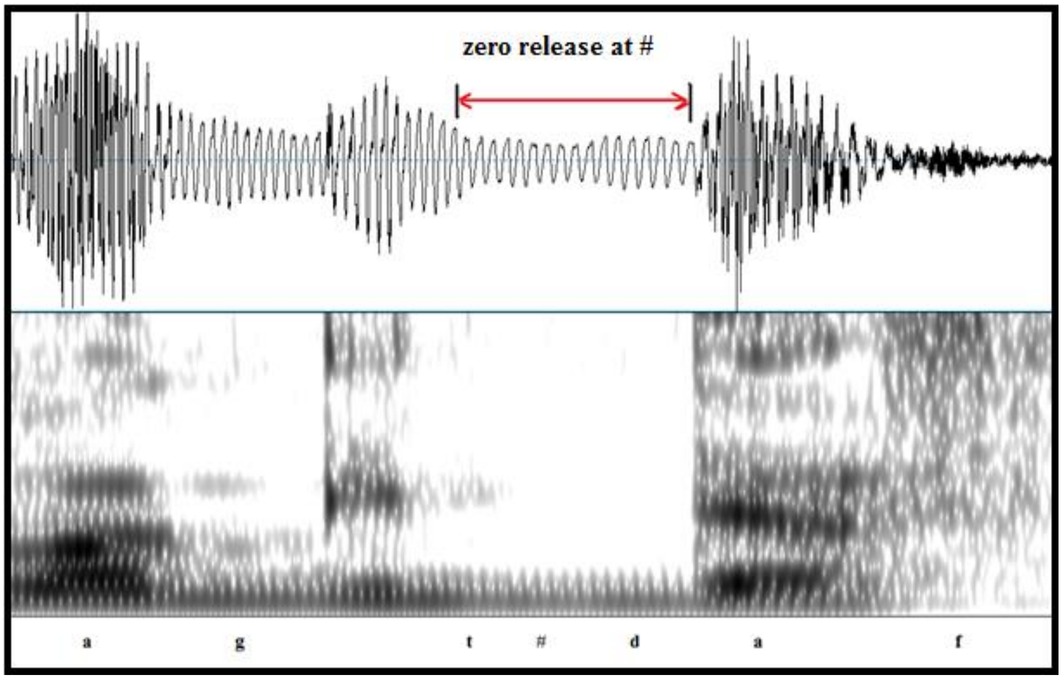


Figure 5.11 Stop closure overlap at word boundary in CC#C homorganic sequence /wagt#daf/ at normal speech rate

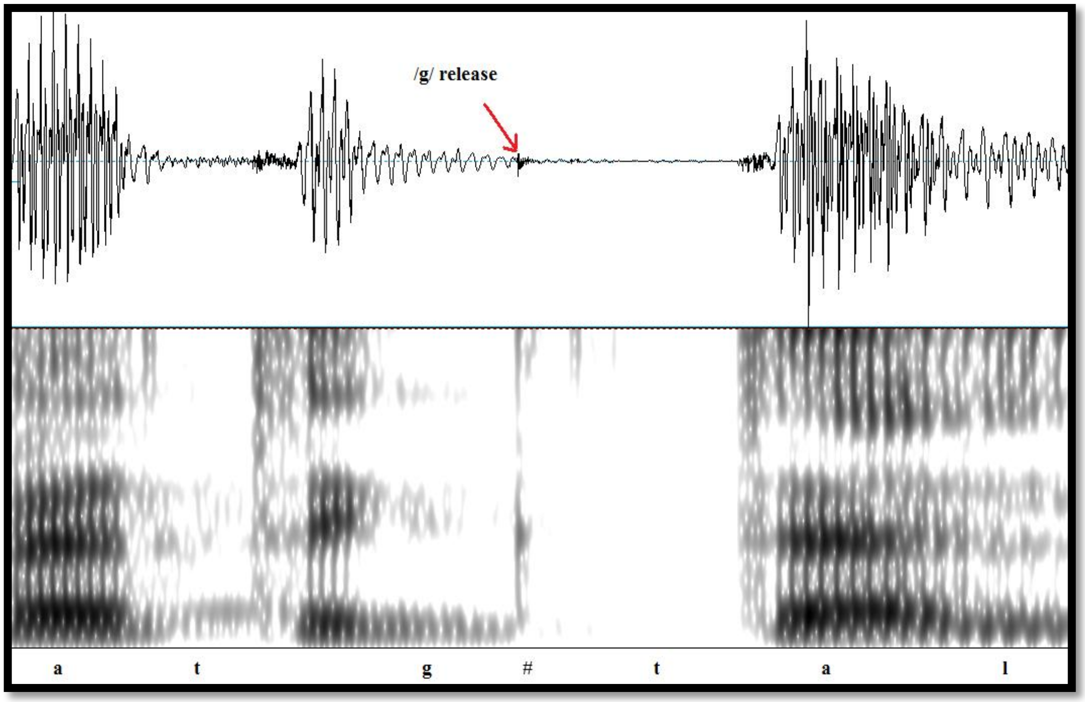


Figure 5.12 Unmasked stop release at word boundary of CC#C heterorganic sequence /fatg#tal/ at normal speech rate

5.3.1.4 Release percentage of stops in CC#CC sequence

The results presented in tables 5.20 and 5.21 indicate that stop gestures across the word boundary in the CC#CC sequence are characterised by a high percentage of unmasked releases of the SF C2 stop even in tokens consisting of homorganic sequences in this position. This pattern is very similar to the one found across the word boundary of the C#CC sequence in section 5.3.1.2. At normal speech rate, stop closure overlap across the word boundary occurred in only 47 repetitions. These instances were exhibited by homorganic sequences only mostly in coronal#coronal sequences. All heterorganic sequences spanning the word boundary exhibited unmasked SF C2 releases (figure 5.13). In /wagt#tkasir/ where a homorganic sequence spanned the word boundary, 5 repetitions exhibited a lack of release of the alveolar /t/ HP. Similarly, 8 repetitions of /wagt#dkar/ exhibited the same pattern. The highest numbers of stop closure overlap across the word boundary were found in /ʕagd#tkasir/ and /ʕagd#dkar/, where 9 repetitions in the former and 11 repetitions of the latter exhibited stop closure overlap across the word boundary. As for the dorsal#dorsal across word boundary homorganic sequences in /fatg#ktir/ and /fatg#gdi:m/, 3 repetitions in each sequence exhibited stop closure overlap across the word boundary. In addition, stop closure overlap was also found in 5 repetitions of /hatk#ktir/ (figure 5.14) and 3 repetitions of /hatk#gdi:m/. These results show that gestural coordination across the word boundary in the CC#CC sequence is relatively weak.

Stops in both SF and SI clusters in this sequence also exhibited a high percentage of unmasked stop releases. It seems to be the case that SF C1 and SI C1 are always released before the closures of their respective following stops are formed. The only instance where stop closure overlap did occurr was between stops of the SF and SI clusters of /ʕagd#dkar/. This occurred in a single repetition produced by speaker 1 at normal speech rate.

Normal							
Token	**SF rls**	**% rls**	**# rls**	**% rls**	**SI rls**	**% rls**	**N**
wagt#tkasir	30	100	25	83	30	100	30
wagt#dkar	30	100	22	73	30	100	30
wagt#ktab	30	100	30	100	30	100	30
wagt#gdi:m	30	100	30	100	30	100	30
ʔagd#tkasir	30	100	21	70	30	100	30
ʔagd#dkar	29	96	19	63	29	96	30
ʔagd#ktab	30	100	30	100	30	100	30
ʔagd#gdi:m	30	100	30	100	30	100	30
hatk#tkasir	30	100	30	100	30	100	30
hatk#dkar	30	100	30	100	30	100	30
hatk#ktir	30	100	25	83	30	100	30
hatk#gdim	30	100	27	90	30	100	30
fatg#tkasir	30	100	30	100	30	100	30
fatg#dkar	30	100	30	100	30	100	30
fatg#ktir	30	100	27	90	30	100	30
fatg#gdi:m	30	100	27	90	30	100	30
Mean	**479**	**99.7%**	**433**	**90%**	**479**	**99.7%**	**480**

Table 5.20 Number of unmasked releases between stops in SF cluster, across word boundary, and in SI cluster of CC#CC sequence tokens at normal speech rate

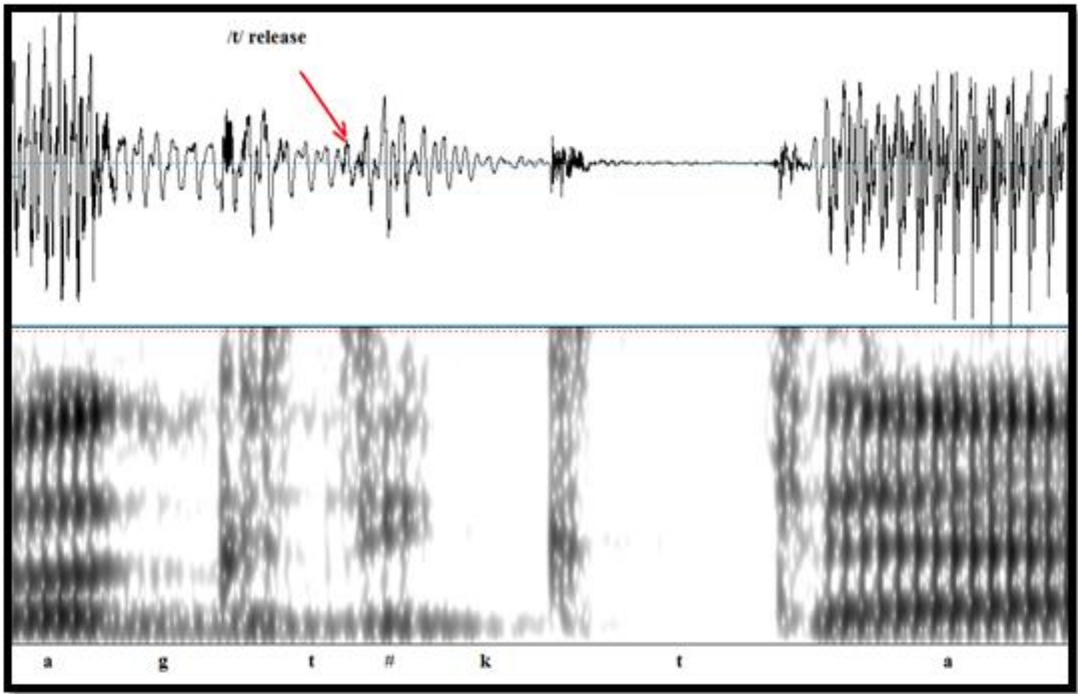


Figure 5.13 Unmasked SF C2 stop release at word boundary in CC#CC heterorganic sequence /wagt#ktab/ at normal speech rate

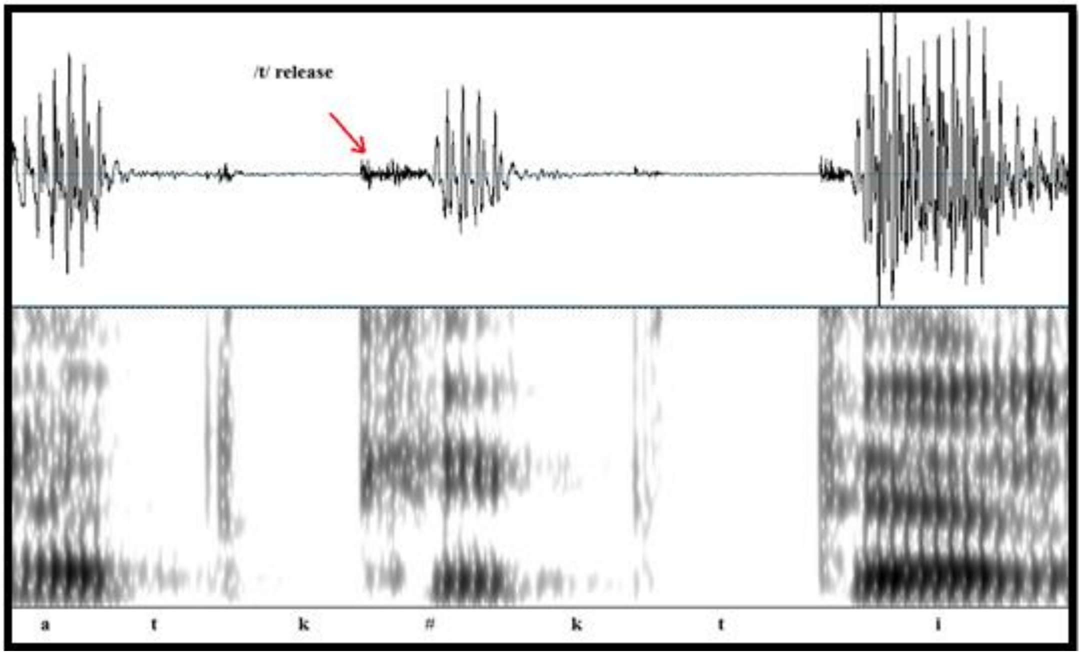


Figure 5.14 Unmasked SF C2 stop release at word boundary in CC#CC homorganic sequence /hatk#ktir/ at normal speech rate

The fast speech rate also exhibited the same unmasked stop release pattern. The increase in speech rate did not result in a significant increase in stop closure overlap in all three positions of the CC#CC sequence. In fact, the number of repetitions exhibiting stop closure overlap across the word boundary decreased to 42 at fast speech rate compared to 47 in normal speech rate. However, stop closure overlap between stops of the SF and SI clusters increased to 7 repetitions in both SF and SI clusters at fast speech rate compared to 1 repetition in normal speech rate.

Fast							
Token	**SF rls**	**% rls**	**# rls**	**% rls**	**SI rls**	**% rls**	**N**
wagt#tkasir	30	100	21	70	30	100	30
wagt#dkar	28	93	24	80	30	100	30
wagt#ktab	30	100	30	100	30	100	30
wagt#gdiːm	30	100	30	100	30	100	30
ʔagd#tkasir	28	93	24	80	30	100	30
ʔagd#dkar	29	96	24	80	30	100	30
ʔagd#ktab	29	96	30	100	28	93	30
ʔagd#gdiːm	29	96	30	100	30	100	30
hatk#tkasir	30	100	30	100	30	100	30
hatk#dkar	30	100	30	100	29	96	30
hatk#ktir	30	100	27	90	28	93	30
hatk#gdim	30	100	27	90	30	100	30
fatg#tkasir	30	100	30	100	30	100	30
fatg#dkar	30	100	30	100	30	100	30
fatg#ktir	30	100	24	80	30	100	30
fatg#gdiːm	30	100	27	90	28	93	30
Mean	**473**	**98%**	**438**	**91%**	**473**	**98%**	**480**

Table 5.21 Unmasked releases between stops in SF cluster, across word boundary, and in SI cluster of CC#CC sequence tokens at fast speech rate

Variability amongst speakers was also observed with speakers 2, 3, 7, and 9 exhibiting a decrease in the percentage of unmasked SF C2 stop releases across the word boundary in normal speech rate. In the case of speakers 2 and 3, the unmasked SF C2 stops release percentage in the normal speech rate was 66% and 68% respectively demonstrating closer gestural coordination.

5.3.1.5 Statistical analysis

As with the EPG data, a one-way ANOVA test was conducted on the pattern of stop releases across the word boundary for all four sequences. The Shapiro-Wilk test for normality showed a significant difference of >0.05 indicating normal distribution of the data. A one-way ANOVA test was performed to check for significant differences between the mean percentage releases for all speakers in the four sequences at both normal and fast speech rates. Furthermore, a Bonferroni Post Hoc statistical test was used to compare between the mean percentages of release of the SF stop preceding the word boundary for all four sequence types. The results are presented in table 5.22.

Results of the test indicate that no significant differences ($p>0.05$) existed between the pattern of stop release across the word boundary in the C#C and CC#C sequences. This indicates that stop closure overlap patterns between stops adjacent to the word boundary in both these sequences were similar. Results also reveal that there was no significant differences ($p>0.05$) between stop releases across the word boundary in the C#CC and CC#CC sequences. However, a significant value of $p<0.05$ was found between stop releases across the word boundary of the C#C sequence and both the C#CC and CC#CC sequences. Furthermore, a similar significant difference ($p<0.05$) was also found between stop releases across the word boundary of the CC#C and both the C#CC and CC#CC sequences. These results are consistent with the test carried out on the EPG data (section 4.3.1.5). The results indicate that in terms of stop releases across the word boundary two distinct categories can be identified. The first category includes tokens of both the C#C and CC#C sequences where tighter gestural coordination across the word boundary was exhibited. The second category includes tokens in both the C#CC and CC#CC sequences with less gestural coordination across the word boundary as displayed in the increase of stop releases in this position.

Multiple Comparisons

Dependent Variable: Unmasked release
Bonferroni

(I) Sequence type		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C#C	C#CC	.421*	.026	.000	.35	.49
	CC#C	.004	.026	1.000	-.07	.07
	CC#CC	.408*	.026	.000	.34	.48
C#CC	C#C	-.421*	.026	.000	-.49	-.35
	CC#C	-.417*	.026	.000	-.49	-.35
	CC#CC	-.013	.026	1.000	-.08	.06
CC#C	C#C	-.004	.026	1.000	-.07	.07
	C#CC	.417*	.026	.000	.35	.49
	CC#CC	.404*	.026	.000	.33	.47
CC#CC	C#C	-.408*	.026	.000	-.48	-.34
	C#CC	.013	.026	1.000	-.06	.08
	CC#C	-.404*	.026	.000	-.47	-.33

***. The mean difference is significant at the 0.05 level.**

Table 5.22 Summary of significant effects in the Post Hoc statistical analysis of unmasked releases at word boundary in C#C, C#CC CC#C, and CC#CC sequences at normal speech rate

At fast speech rate, the one-way ANOVA also showed a significant difference of $p<0.05$ but the significance pattern was not consistent with that for the normal speech rate. The Bonferroni Post Hoc test shows that a no significant difference value of $p=1.000$ was observed between stop releases in the C#C and CC#C sequences in line with normal speech rate. However, contrary to normal speech rate, a significant value of $p=0.001$ was found between stop releases across the word boundary in the C#CC sequence and the CC#CC sequence. Furthermore, a significant value of $p<0.05$ was found between stop releases in the C#CC sequence and both the C#C and CC#C sequences. These significance results are not consistent with the results found in the normal speech rate. The increase in the speech rate resulted in a decrease in stop releases across word boundary in the C#CC sequence as highlighted in table 5.18. This seems to have resulted in a significant difference being exhibited compared to stop releases across the word boundary in the CC#CC sequence. In normal speech rate, both these sequences belonged to the same category in terms of stop releases occurring across the word boundary.

As for the productions of individual speakers, the one-way ANOVA test also resulted in a significant difference of $p<0.05$ for each speaker. A Bonferroni Post Hoc test was applied to both the normal and fast speech rate productions of each speaker separately in order to identify significant differences between sequences. Speakers 1, 5, 6, 7, 8, 9, and 10 exhibited the same significance results in normal and fast speech rates. For these speakers, stop releases across word boundary in the C#C and CC#C sequences were not significantly different from each other. Furthermore, in both the C#CC and CC#CC sequences, stop releases across word boundary in these sequences were not significantly different. However, the results for the C#C and CC#C sequences on one hand were significantly different from the results in both the C#CC and CC#CC sequences on the other hand highlighting two different categories of gestural coordination across the word boundary as previously found in the general pattern for the normal speech rate.

Variations between speakers were found in the statistical results between speakers 2, 3, and 4. In the case of speaker 2, results of the Bonferroni Post Hoc test for the normal speech rate showed that there was no significant difference with a value of $p=1.000$ between stop releases across the word boundary in the C#C and CC#C sequences. However, a significant difference with a value of $p=0.044$ was found between stop releases in the C#CC and CC#CC sequences as opposed to the overall pattern. Furthermore, a no significant value of $p=0.200$ was found between stop releases in the C#C and CC#CC sequence and a no significant value of $p=0.433$ was found between releases in the CC#C and CC#CC sequences. These results show that in normal speech rate of speaker 2, there was an increase in stop closure overlap across the word boundary in the CC#CC sequence resulting in a pattern similar to stop releases in the C#C and CC#C sequences.

However, this pattern for speaker 2 was completely different at fast speech rate. In this case, the Bonferroni Post Hoc test showed that there was no significant difference (*p*=1.000) between stop releases in the C#C and CC#C sequences or between the C#C and the C#CC word boundary sequences (*p*=0.359). However, a significant difference was found between stop releases in the CC#CC sequence and in all the other three sequences.

As for speaker 3, the Bonferroni Post Hoc test shows that there was no significant difference between stop releases across the word boundary in all four sequence types at fast speech rate.

Finally, in the case of speaker 4, at normal speech rate a Bonferroni Post Hoc test showed that no significant difference in stop releases across the word boundary with a value of *p=0.107* found between the C#C and the C#CC. Stop releases across the word boundary in both these sequences where significantly different from each whereas they are not significantly different according to the overall pattern.

5.3.1.6 Summary

The acoustic data reveals that different sequences exhibit varying degrees of gestural coordination between adjacent stops. With regards to the pattern exhibited across the word boundaries of the four sequence types investigated, the statistical results indicate that two different categories can be identified. In terms of the number of stop closure overlap occurring across the word boundary; both the C#C and CC#C sequences are very similar. Both sequences exhibited closer gestural articulation reflected in the lower percentage of unmasked releases and therefore greater stop closure overlap occurring across their boundaries. For both sequences, stop closure overlap between gestures of stops spanning the word boundary occurred in all the homorganic tokens.

On the other hand, the C#CC and CC#CC sequences both belong to the second category in terms of the number of unmasked stop releases occurring across the word boundary. The number of stop closure overlap occurring across the word boundary in tokens of both these sequences was almost negligible. Unmasked stop releases across the word boundary were also found to occur in homorganic stop sequences spanning the word boundary. The HP's of stops spanning the word boundary in both sequences are not closely coordinated resulting in a visible acoustic release and therefore less gestural coordination. These results are in line with the results of section 4.3.1 of the EPG data.

The increase in speech rate did not have a significant effect on the pattern of stop closure overlap in all four sequences. The percentage of unmasked stop releases remained stable in both normal and fast speech rates. The overall pattern of masked and unmasked stop releases occurring across the word boundaries of the four sequence types is illustrated in figures 5.15 and 5.16.

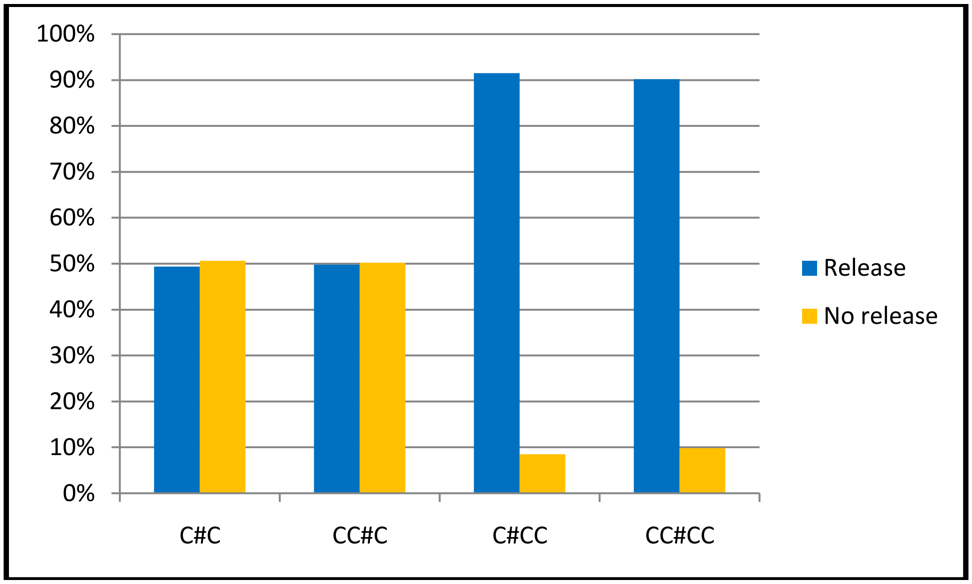


Figure 5.15 Percentage of masked and unmasked stop releases across word boundary in normal speech rate

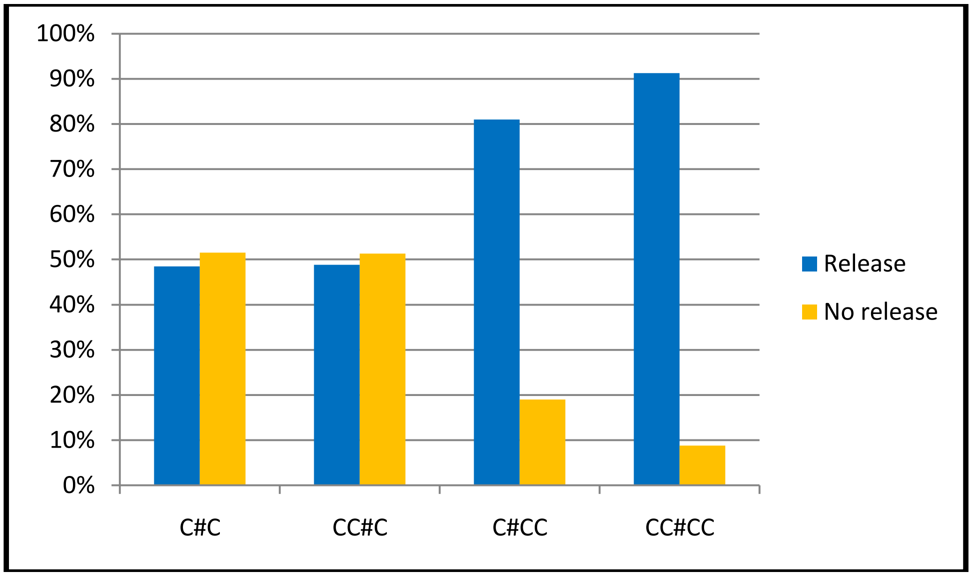


Figure 5.16 Percentage of masked and unmasked stop releases across word boundary in fast speech rate

In terms of the number of stop releases between stops of the SF and SI clusters of the C#CC, CC#C, and CC#CC sequences, a high number of unmasked stop releases occurred between stops of the SF and SI clusters in all four sequences. These results for the number of unmasked stop releases occurring in the SF cluster of the CC#C sequence are consistent with those for the EPG data (section 4.3.1.3) both exhibiting 100% unmasked stop releases. However, the percentage of unmasked stop releases within the SI cluster of the C#CC sequence was 100% in normal speech rate whereas in the EPG data this percentage was 70%. Furthermore, in the SF and SI cluster of the CC#CC sequence, the percentage of unmasked stop releases in normal speech rate was 99% for both positions whereas these were 55% and 52% respectively in the EPG data.

As previously mentioned, these results do not imply that stop gestures are not coordinated with each other but simply indicate that the HP's of both stop gestures do not exhibit overlap. The following section investigates the degree of gestural coordination between stops in terms of ICI duration. The duration of the ICI resulting from these releases provides further information on the degree of gestural coordination in terms of the lag duration between the release of a stop gesture and the closure of the following stop.

5.3.2 ICI durations and distribution patterns in stop sequences

Having identified different gestural coordination patterns between stops in the four sequence types in the previous section, this section presents the results of ICI durations occurring between adjacent stops as a result of the unmasked releases in the four sequence types. The degree of gestural coordination is calculated in terms of the articulatory lag between release of C1 HP and C2 closure. Results of the durations of SF, SI, and word boundary ICIs of the four sequence types indicate the degree of gestural coordination between stops. The ICI duration between any two stops C1C2 is identified as the interval between the acoustic release of the HP of C1 and the onset of closure of C2.

5.3.2.1 ICI duration and distribution in two-stop C#C sequence

Table 5.23 presents the results of the ICI duration occurring across the word boundary between the SF single articulatory gesture stop and the SI singleton in cases where the release of the SF stop was unmasked. The results indicate that the lag duration is short resulting in closer gestural coordination between both stop gestures. The mean ICI duration across all tokens was 14ms at both speech rates.

The longest mean lag duration of 20ms is found at the word boundary of /dag#tal/ in normal speech rate. Here the TB and the TT gestures are pulled apart more resulting in a longer ICI duration between both HP's. This is also the case in other tokens where a TB gesture is followed by a TT gesture such as /dag#dam/, /fak#tal/, and /fak#dam/. All these tokens exhibited longer lag durations and therefore lesser degrees of gestural coordination. The shortest ICIs occurred at the word boundary in /ʒit#giʃ/ and /ʃid#giʃ/ where a TT gesture is followed by a TB gesture. However, the difference in ICI duration is not considerable.

	Normal			Fast		
Token	**Mean ICI**	**N**	**Std. Dev.**	**Mean ICI**	**N**	**Std. Dev.**
ʒit#tal	--	0	--	--	0	--
ʒit#dis	--	0	--	--	0	--
ʒit#kalb	10	30	5	8	30	3
ʒit#giʃ	9	29	5	8	30	4
ʃid#tal	--	0	--	--	0	--
ʃid#dis	--	0	--	--	0	--
ʃid#kif	11	30	5	11	30	6
ʃid#giʃ	9	29	7	7	26	5
fak#tal	19	30	6	19	29	6
fak#dam	18	29	8	19	30	8
fak#kif	--	0	--	--	0	--
fak#giʃ	--	0	--	--	0	--
dag#tal	20	30	8	18	29	5
dag#dam	19	30	7	19	29	6
dag#kif	--	0	--	--	0	--
dag#giʃ	--	0	--	--	0	--
Total	**14ms**	**237**	**8**	**14ms**	**233**	**7**

Table 5.23 Mean ICI durations at word boundary of C#C sequence at normal and fast rates

Furthermore, the increase in speech rate did not have a significant effect on gestural coordination. In fast speech rate, the degree of gestural coordination did not increase between stop gestures as highlighted by the negligible decrease in ICI duration in fast speech rates. These results are also in line with results the EPG data (section 4.3.2.1).

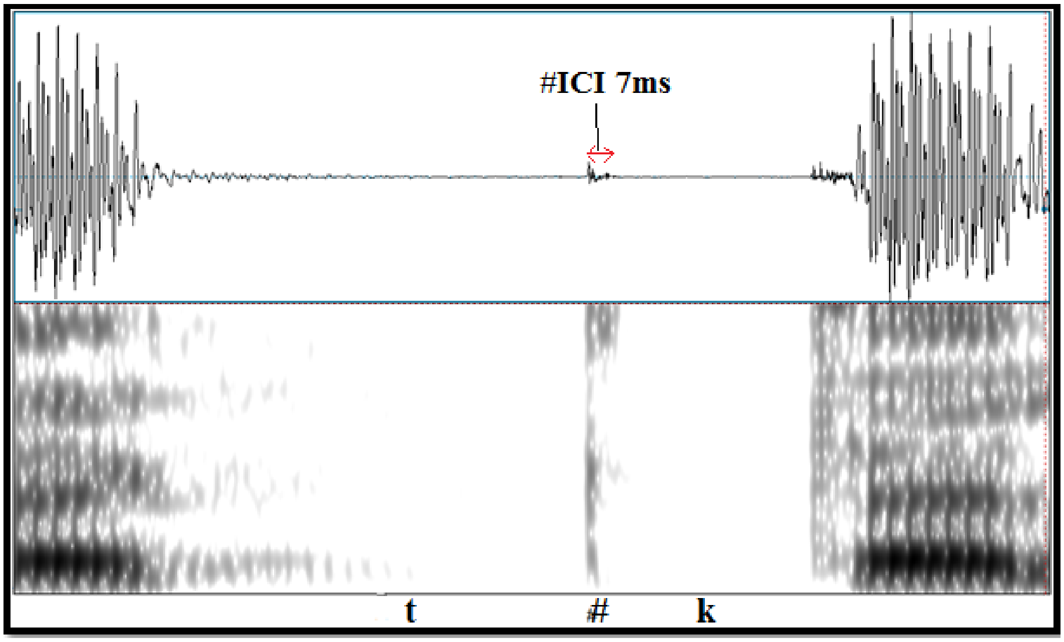


Figure 5.17 ICI in /ʒit#kalb/ measuring 7ms in normal speech rate

In both normal and fast speech rates, tighter gestural coordination between stops across the word boundary in all tokens of the C#C sequence was exhibited by all 10 speakers. This is reflected by the short ICI durations in table 5.24. However, relatively longer lag durations and therefore a slight decrease in gestural coordination across the word boundary is exhibited by speakers 7 and 10 when compared to the other speakers.

	Normal			Fast		
Speaker	Mean ICI (ms)	N	Std. Dev.	Mean ICI (ms)	N	Std. Dev.
Speaker 1	11	22	8	11	22	7
Speaker 2	10	23	6	14	22	9
Speaker 3	11	24	4	12	24	6
Speaker 4	13	24	8	12	24	8
Speaker 5	10	24	5	11	24	6
Speaker 6	14	24	5	11	22	5
Speaker 7	21	24	8	19	24	5
Speaker 8	16	24	6	15	24	5
Speaker 9	11	24	7	8	23	6
Speaker 10	24	24	9	19	24	1

Table 5.24 Mean #ICI in C#C sequence across all tokens

5.3.2.2 ICI duration and distribution in three-stop C#CC sequence

In the C#CC sequence, there are two positions in which the ICI resulting from unmasked stop releases may occur, namely, between stops adjacent to the word boundary and within the SI cluster. The results presented in table 5.25 reveal that gestural coordination differs in these locations. In normal speech rate, the mean ICI occurring at the word boundary across all tokens averaged 47ms whilst within the SI cluster it averaged 16ms. Stop gestures spanning the word boundary exhibit a significant decrease in gestural coordination in comparison with the coordination pattern in the C#C sequence described in the previous section. Here gestures are further pulled apart as a result of the long lag durations occurring across the word boundary. However, stops of the SI cluster exhibit shorter lag durations similar to those found in the previous section in C#C which indicates that the degree of gestural coordination between SI stops is very tight.

Normal						
Token	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std Dev**
bat#tkasir	38	15	18	15	30	6
nat#dkar	49	21	15	13	30	7
nat#kdab	35	30	9	18	30	7
nat#gtal	40	30	8	19	30	7
ʃad#tkasir	46	21	15	14	30	5
ʃad#dkar	50	22	14	15	30	7
ʃad#ktir	38	30	9	20	30	7
ʃad#gtal	38	30	8	20	30	4
fak#tkasir	41	30	10	12	30	6
fak#dkar	48	30	10	13	30	5
fak#ktir	61	30	15	19	30	5
fak#gtal	59	30	11	18	30	8
ʃag#tkasir	47	30	9	11	30	7
hag#dkar	49	30	6	13	30	6
nag#ktir	58	30	11	20	30	6
hag#gdi:m	58	30	15	17	30	8
Mean	**47ms**	**439**	**14**	**16ms**	**480**	**7**

Table 5.25 Mean ICI durations at word boundary and SI cluster of C#CC sequence at normal speech rate

This pattern is evident in all tokens of this sequence. The lag duration between stops spanning the word boundary is at least double the lag duration found between stops of the SI cluster as highlighted in /fak#tkasir/ figure 5.18. In normal speech rate, the mean #ICI duration was 38ms whereas the SI ICI was 20ms in /ʃad#gtal/ revealing how stop gestures across the word boundary are pulled apart further compared to those in the SI cluster. In /fak#ktir/, despite the fact that both stops spanning the word boundary are TB gesture stops, the mean ICI averaged 61ms. The mean ICI duration occurring at the word boundary ranged from 35ms to 61ms. The mean ICI duration within the SI cluster was significantly shorter ranging from 11ms to 20ms. This gestural coordination pattern is also exhibited by all ten speakers as presented in table 5.26.

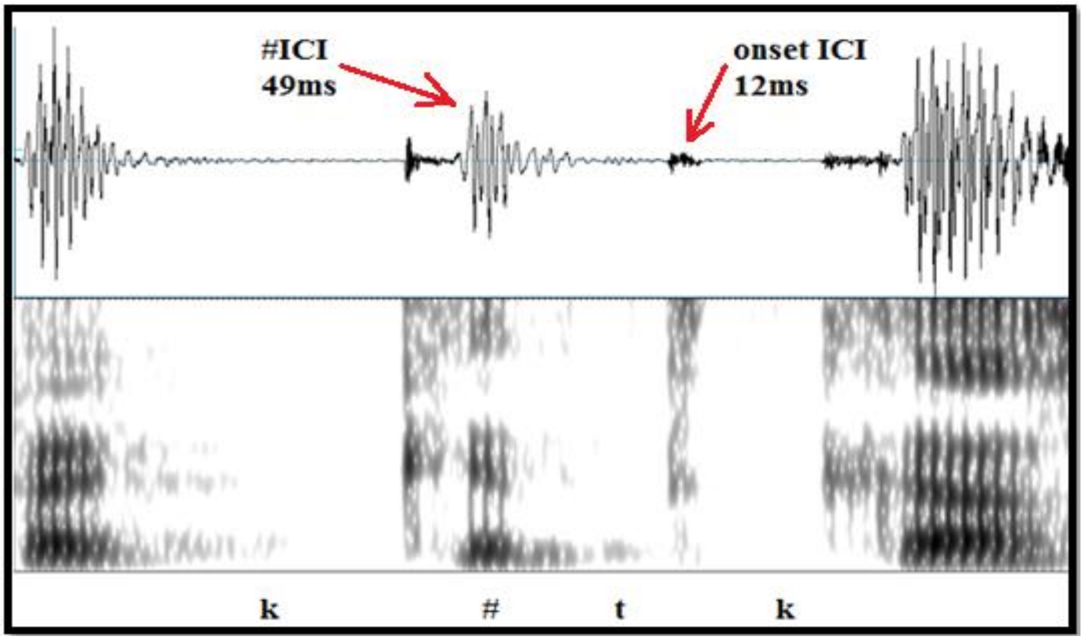


Figure 5.18 #ICI and SI ICI in /fak#tkasir/ at normal speech rate

Normal						
Token	**Mean # ICI (ms)**	**N**	**Std Dev**	**Mean SI ICI (ms)**	**N**	**Std Dev**
Speaker 1	47	48	13	16	48	6
Speaker 2	50	44	14	13	48	6
Speaker 3	37	36	11	11	48	4
Speaker 4	50	47	11	13	48	6
Speaker 5	51	48	11	12	48	5
Speaker 6	50	48	8	17	48	5
Speaker 7	54	36	17	21	48	6
Speaker 8	46	42	15	16	48	6
Speaker 9	32	42	13	14	48	6
Speaker 10	50	48	11	24	48	6

Table 5.26 Mean #ICI and SI ICI in C#CC sequence across all tokens at normal speech rate

The ICI distribution pattern in both positions of the C#CC sequence did not differ as a result of an increase in speech rate. In fast speech rate, longer ICI durations are also found across the word boundary suggesting weaker gestural coordination whereas shorter lag durations occur between stops of the SI cluster as presented in table 5.27.

Fast						
Token	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std Dev**
bat#tkasir	31	4	18	11	30	3
nat#dkar	38	14	12	12	30	3
nat#kdab	24	30	9	17	30	8
nat#gtal	29	30	7	15	28	7
ʃad#tkasir	36	18	16	12	30	5
ʃad#dkar	43	15	10	14	30	4
ʃad#ktir	34	30	10	18	30	6
ʃad#gtal	30	30	7	16	29	6
fak#tkasir	35	30	10	11	29	7
fak#dkar	34	30	9	12	30	7
fak#ktir	48	22	17	19	29	5
fak#gtal	48	23	13	17	30	6
ʃag#tkasir	36	30	6	11	30	5
hag#dkar	36	30	9	12	29	6
nag#ktir	46	27	10	19	30	6
hag#gdi:m	47	26	12	19	30	7
Mean	**37ms**	**389**	**13**	**15ms**	**474**	**6**

Table 5.27 Mean ICI durations at word boundary and SI cluster of C#CC sequence fast speech rate

Despite the stability in the gestural coordination pattern, the ICI duration between stops spanning the word boundary did exhibit a decrease in comparison to the normal speech rate suggesting closer gestural coordination resulting from the increase in speech rate. However, a similar effect is not found in the lag durations and ICIs occurring between stops of the SI cluster. The mean word boundary lag duration decreased to 37ms in fast speech rate compared to 47ms in normal speech rate. On the other hand, the ICI occurring between stops of the SI cluster remained stable averaging 15ms in fast speech rate compared to 16ms in normal speech rate. This was also found previously when investigating the ICI occurring in the word boundary of the C#C sequence. This effect, as a result of the increase in speech rate is also exhibited by the productions of all 10 speakers. Please refer to Appendix A for the fast speech rate of individual speakers. In general, tokens of the C#CC sequence exhibited tighter coordination within the SI cluster and weaker gestural coordination between stops spanning the word boundary in both speech rates.

5.3.2.3 ICI duration and distribution in three-stop CC#C sequence

Like C#CC, this sequence also consists of a three stop C1C2C3 sequence with two possible positions for an ICI interval to occur: within the SF cluster or between stops adjacent to the word boundary. The only difference lies in the location of the word boundary. Here the word boundary is located between C2 and C3 of the sequence as opposed to being between C1 and C2 in the C#CC sequence.

Results show that there is a considerable difference between ICI durations occurring in both locations in this sequence (table 5.28). Unlike the C#CC sequence where weak gestural coordination was reflected in long lag durations occurring between stops adjacent to the word boundary, ICI durations occurring at the word boundary in the CC#C sequence were significantly shorter indicating tighter gestural coordination during the articulation of these stops. In normal speech rate, the mean #ICI duration was 15ms. Furthermore, demonstrating this tight coordination pattern between stop gestures in this position, all homorganic sequences across the word boundary are characterized by zero lag durations as a result of stop closure overlap as previously explained (section 5.3.1.3). The ICI occurring across the word boundary ranged from 10ms to 19ms. These durations are similar to the lag durations exhibited across the word boundary of the C#C sequence (section 5.3.2.1). The longest mean lag duration found here is 19ms, which is found in /fatg#tal/ and /hatk#tal/ where a TB stop gesture is followed by a TT stop gesture across the word boundary. Closer gestural coordination across the word boundary is found in /wagt#giʃ/ and /ʕagd#gas/ with a mean lag duration of 10ms occurring between the TT stop gesture and TB stop gesture.

Normal						
Token	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**
wagt#tal	41	30	9	--	0	--
wagt#daf	41	30	10	--	0	--
wagt#kif	44	30	7	11	30	6
wagt#giʃ	43	30	6	10	29	7
ʕagd#tal	46	30	6	--	0	--
ʕagd#dam	44	30	8	--	0	--
ʕagd#kam	45	30	8	11	30	6
ʕagd#gas	43	30	9	10	30	7
hatk#tal	38	30	7	19	30	6
hatk#dam	39	30	7	18	30	4
hatk#kif	48	30	12	--	0	--
hatk#giʃ	45	30	12	--	0	--
fatg#tal	42	30	11	19	30	6
fatg#dam	41	30	9	18	30	5
fatg#kam	46	30	13	--	0	--
fatg#gal	45	30	10	--	0	--
Mean	**43ms**	**480**	**9**	**15ms**	**239**	**9**

Table 5.28 Mean ICI durations at SF and word boundary of CC#C sequence at normal speech rate

On the other hand, a different gestural coordination pattern is found between stops of the SF cluster in the CC#C sequence. Gestural coordination between stops in this position is characterized by longer lag durations averaging 43ms. The mean ICI duration occurring between stops of the SF cluster ranged from 38ms to 48ms. This coordination pattern is similar to the coordination pattern occurring between stops adjacent to the word boundary in the C#CC sequence of the previous section. Stop gestures here are further pulled apart as a result of the weak coordination between stop gestures. This resulted in longer lag duration and therefore longer ICI durations than those occurring across the word boundary.

In /ʕagd#kam/ in figure 5.19, the mean ICI duration occurring between stops of the SF cluster averaged 45ms in an indication that the HP's of both these stops are relatively pulled apart. On the other hand, the mean ICI duration occurring between the TT and TB gesture stops spanning the word boundary averaged only 11ms, thereby exhibiting an increase in the degree of gestural coordination. In /hatk#kif/, the lag duration between stops of the SF cluster increased to 48ms. However, as a result of the fake geminate occurring across the word boundary, no ICIs existed in this position.

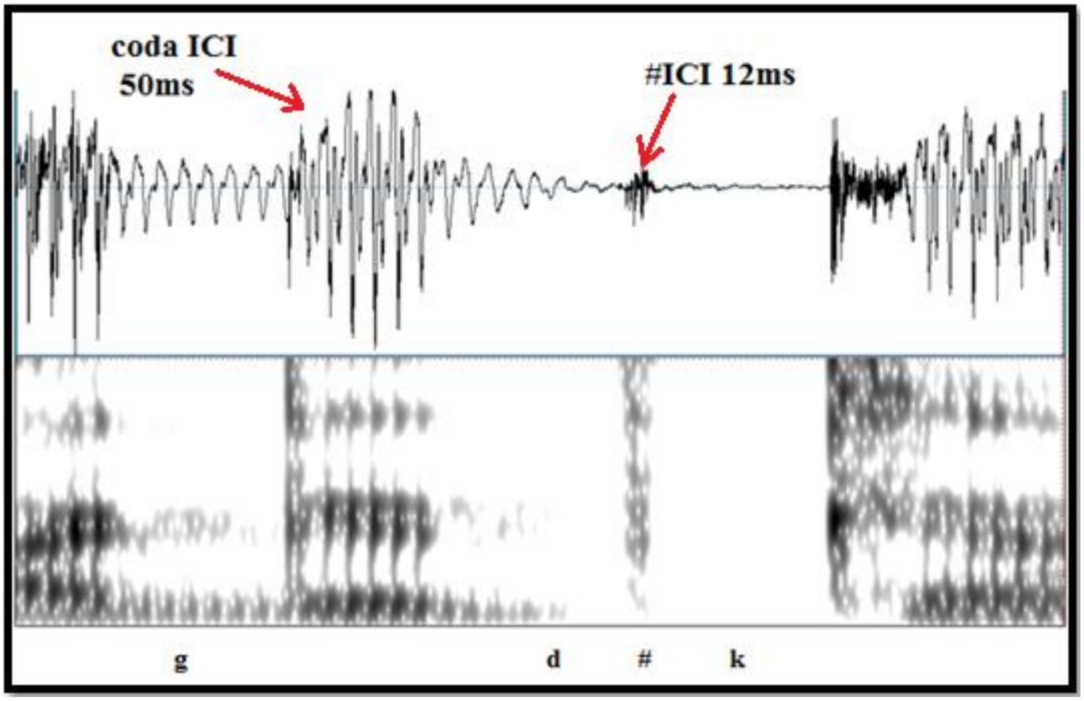


Figure 5.19 SF ICI and #ICI in /ʕagd#kam/ at normal speech rate

This gestural coordination pattern between stops of the CC#C sequence was reflected in the individual productions of the ten speakers as highlighted by the ICI durations in table 5.29. However, an increase in gestural coordination between stops adjacent to the word boundary is found in speaker 7 where the mean ICI duration averaged 24ms. The lag durations in the SF cluster for all ten speakers ranged from 33ms to 51ms. Gestural coordination across the word boundary resulted in a mean ICI duration ranging from 11ms to 24ms.

Normal						
Speaker	**Mean SF ICI (ms)**	**N**	**Std Dev**	**Mean # ICI (ms)**	**N**	**Std Dev**
Speaker 1	38	4	9	12	24	6
Speaker 2	51	4	7	13	24	6
Speaker 3	43	4	9	12	24	6
Speaker 4	41	4	8	12	24	7
Speaker 5	48	4	7	13	24	7
Speaker 6	45	4	8	14	24	5
Speaker 7	37	4	7	24	24	3
Speaker 8	45	4	6	11	24	3
Speaker 9	33	4	6	15	23	8
Speaker 10	51	4	8	19	24	6

Table 5.29 Mean SF ICI and # ICI in CC#C sequence across all tokens

Table 5.30 presents the results of the mean lag durations occurring between adjacent stops of the CC#C sequence in fast speech rate. The increase in speech rate caused a similar effect on the degree of gestural coordination as that occurring in the previous C#CC sequence. At fast speech rate the same gestural coordination pattern was found where gestures of the SF stops lack tight gestural coordination and gestures of stops spanning the word boundary exhibited shorter ICI. However, the increase in speech rate resulted in closer gestural coordination in the SF position where the stops gestures were pulled apart in normal speech rate. The mean ICI duration occurring between stops of the SF cluster decreased to 29ms as opposed to 43ms in the normal speech rate. The gestural coordination pattern between stops spanning the word boundary was not affected in the same way, however. Here the mean ICI duration remained almost stable at both speech rates with the mean averaging 15ms at normal speech rate and 14ms at fast speech rate. Therefore, it is evident that in both the C#CC and CC#CC sequences, the increase in speech rate only has an effect on the long ICI location in both sequences where gestural coordination is weak resulting in tighter coordination. The results for the C#CC sequence (section 5.3.2.2) revealed that the increase in speech rate did not have any effect on the position where the short lag was found, in this case at the SI cluster. However, the position of the long ICI duration, the word boundary in this case, was affected where gestural coordination increased resulting in a decrease in the ICI duration in this position. These results are in line with the EPG results (sections 4.3.2.2 and 4.3.3.3). Please refer to Appendix A for the fast speech rate of individual speakers.

Fast						
Token	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**
wagt#tal	24	30	8	--	0	--
wagt#daf	23	30	8	--	0	--
wagt#kif	28	30	8	13	30	5
wagt#giʃ	27	30	5	10	30	7
ʕagd#tal	32	30	6	--	0	--
ʕagd#dam	28	30	6	--	0	--
ʕagd#kam	31	30	7	10	30	4
ʕagd#gas	28	30	6	9	26	7
hatk#tal	29	30	7	17	29	6
hatk#dam	28	30	6	21	30	6
hatk#kif	33	30	7	--	0	--
hatk#giʃ	33	30	7	--	0	--
fatg#tal	29	30	6	17	29	6
fatg#dam	30	30	4	18	30	7
fatg#kam	34	30	8	--	0	--
fatg#gal	33	30	8	--	0	--
Mean	**29ms**	**480**	**7**	**14ms**	**234**	**7**

Table 5.30 Mean ICI durations at SF and word boundary of CC#C sequence at fast speech rate

It is worth noting that gestural coordination between stops in the C#CC and CC#C sequences is very similar. As previously mentioned, the similarity between the gestural coordination pattern of stops exhibited in the CC#C and C#CC sequences lies in the fact that there is more gestural lag and therefore a decrease in gestural coordination between C1 and C2 stops of both sequences. Conversely, C2 and C3 stops exhibit tighter gestural coordination and therefore shorter lag duration. Despite having different word boundary locations, the coordination patterns in both sequences are identical. At normal speech rate, the results for the ICIs occurring between stops of the C#CC sequence (section 5.3.2.2) revealed that the mean lag duration between C1 and C2 of the sequence was 47ms whilst between C2 and C3 this was 16ms. Similarly, in the CC#C sequence, the mean lag duration between C1 and C2 averaged 43ms and between C2 and C3 it was 16ms. An example will serve to highlight this similarity in the gestural coordination pattern between stops of both these sequences. Thus, /nat#kdab/ of the C#CC and /hatk#dam/ of the CC#C sequence both consist of the same C1C2C3 stops, namely, /t,k,d/. The only difference between them lies in the location of the word boundary. Despite this, the same degree of gestural coordination is found between these stops in both sequence types. When occurring in the C#CC sequence as in /nat#kdab/, the mean ICI duration between C1 TT /t/ and C2 TB /k/ averaged 35ms, indicating that the gestures are pulled apart. However, a mean ICI duration of 18ms is found between C2 TB /k/ and C3 TT /d/. Furthermore, when the same sequence of stops occurs in /hatk#dam/ of the CC#C sequence, the mean ICI durations between these stops are similar. Here the mean ICI duration between C1 TT /t/ and C2 TB /k/ was 39ms. The mean ICI duration between C2 TB /k/ and C3 TT /d/ was 18ms. This highlights the similarity in the coordination pattern of stop gestures in the CC#C and C#CC sequences as in figure 5.20.

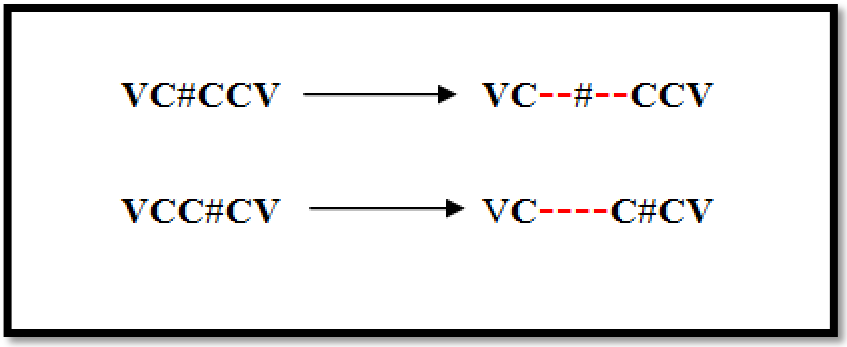


Figure 5.20 Similarity of gestural coordination patterns between stops in the C#CC and CC#C sequences where (----) represents longer lag durations between C1 and C2 stops of both sequences

The following section presents the results of a further investigation into gestural coordination and ICI distribution patterns between stops in the CC#C and C#CC sequences.

5.3.2.3.1 Gestural coordination in C#CC and CC#C sequences

A possible explanation for this similarity in the gestural coordination and ICI distribution pattern between stops in both the C#CC and CC#C sequences found in both the acoustic and the EPG data (section 4.3.2) is that in the CC#C sequence, a resyllabification process occurs by which SF C2 migrates to the other side of the word boundary and forms a SI cluster with SI C1. If this is the case, the resulting configuration is similar to the syllabic configuration of the C#CC sequence as a result of the weak gestural coordination pattern and therefore a longer ICI duration occurs between stops of the SF cluster of the **CC**#C sequence. The hypothesis here is that SF C2 of the C**C**#C sequence migrates to the other side of the boundary and bonds with the SI stop in the environment where the SI stop occurs as a singleton as in figure 5.21.

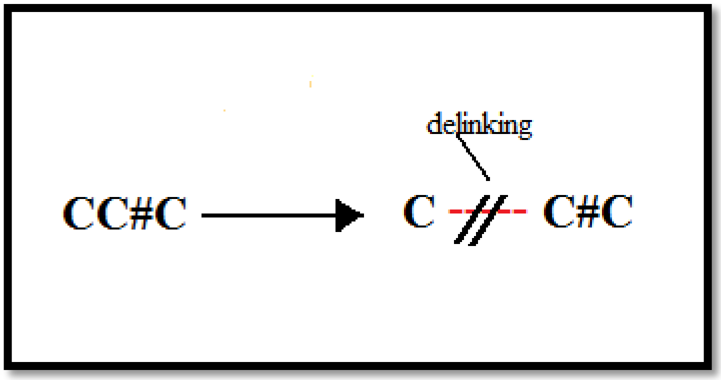


Figure 5.21 Delinking of SF C2 in CC#C sequence and migration to SI position

In order to find evidence for this, a C-centre measurement was applied to compare the durational relationship between clusters and their following vowels. The C-centre hypothesis (Browman & Goldstein 1988) claims that in SI position, consonants are organized and overlap with the following vowel and an increase in the number of consonants in onset position will result in the shortening of the following vowel. In other words, the duration between the midpoint of a singleton SI onset and the offset of a following vowel would be the same as the duration between the midpoint of a SI cluster consisting of two or three consonants to the offset of the following vowel. The actual hypothesis will not be tested to find out whether it applies to TLA or not; the C-centre is simply being used as a unit of measurement.

Consisting of a stable SI cluster, the baseline cluster used here is the SI cluster in the C#**CCV** sequence. This is used as a baseline since it already consists of an SI cluster of two stops, which is the maximum possible according to the syllabic template of TLA of $C_2^1VC_2^0$ and therefore prohibits the occurrence of any migration across the word boundary from SF position to occur. As for the primary sequence under investigation for the resyllabification process, CC#C, here SF C2 is considered to be C1 of a SI cluster and the SI singleton is considered as C2 of the SI cluster as in the following C**C#CV** sequence. Any ICI durations found between C1 and C2 in any of these clusters were included in the total duration of the cluster. The C-centre was calculated by measuring the duration between the midpoints of the above mentioned clusters to the left edge of the following vowel. In addition, the C-centre was also measured in the

C#C sequence where both the SF single articulatory gesture stop and the SI singleton are considered to represent one cluster as in **C#C**V and are therefore measured in relation to the following vowel. The C-centre durations for all tokens in these three sequence types detailed above were calculated and compared. The hypothesis that SF C2 of the C**C**#C sequence migrates to the other side of the boundary and bonds with the SI stop in the environment where the SI stop occurs as a singleton is proved if the C-centre durations in the C**C#CV** and C#**CCV** sequences are found to be similar.

5.3.2.3.2 C-centre in C#CC, CC#C, and C#C sequences

The results of the mean C-centre durations across all speakers in the three sequence types under investigation are presented in table 5.30. In normal speech rate, the mean C-centre to anchor point duration in the baseline sequence C#**CCV** averaged 148ms at the normal speech rate. This was considerably shorter than the mean C-centre to anchor point measured in the **C#CV** sequence where it averaged 176ms at the normal speech rate. However, in viewing the results of the mean C-centre in the C**C#CV** sequence under investigation for SF C2 migration, it can be observed that mean C-centres to the respective anchor points in this sequence and the sequence C#**CCV** consisting of a stable SI cluster are almost identical averaging 148ms in the C#**CCV** sequence and 147ms in the C**C#CV** sequence.

	Normal			**Fast**		
Sequence	Mean	N	Std. Deviation	Mean	N	Std. Deviation
C#CV	176ms	480	11.816	142ms	480	7.212
C#**CCV**	148ms	480	9.746	127ms	480	6.088
C**C#CV**	147ms	480	4.096	127ms	480	7.281

Table 5.30 Mean C-centre to anchor point durations in C#CCV sequence compared to CC#CV and C#CV sequences in normal and fast speech rate across all speakers

The same pattern is also exhibited at the fast speech rate. The mean C-centre to anchor point averaged 142ms in the **C#CV** sequence at fast speech rate whilst for the baseline sequence C#**CCV** this averaged 127ms at the same speech rate. Finally, the mean C-centre in the C**C#CV** sequence under investigation for SF C2 migration also averaged 127ms which is identical to the mean C-centre in the baseline sequence. These results further indicate that both timing and gestural coordination in both the CC#C and C#CC sequences are very similar as highlighted in figure 5.22.

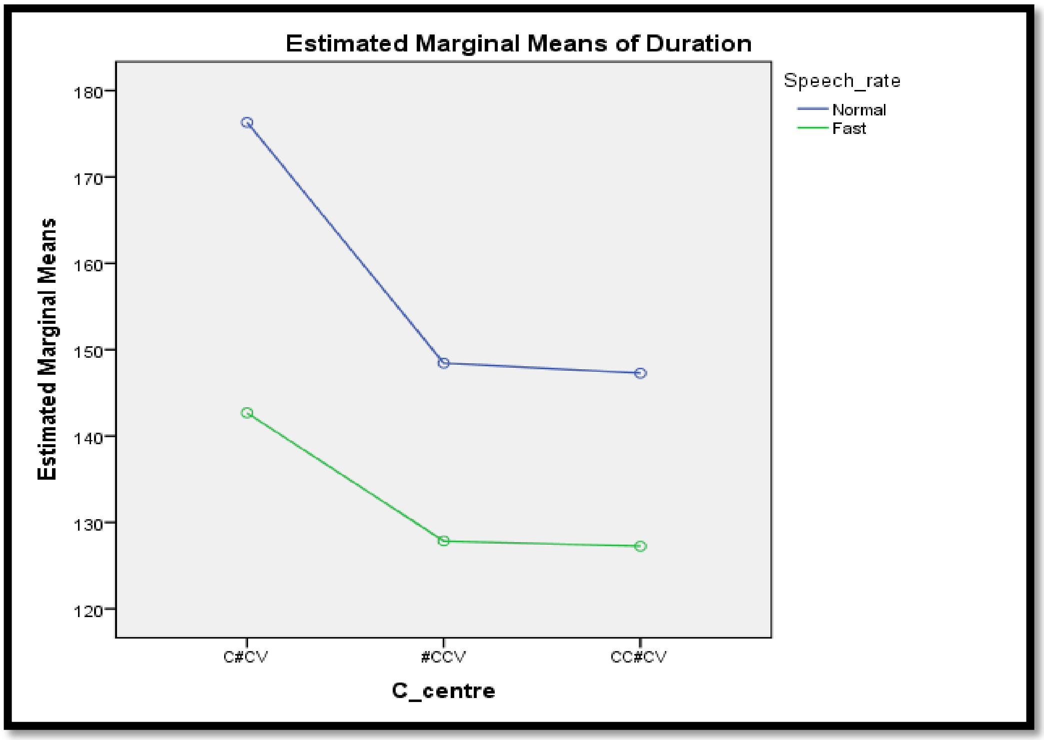


Figure 5.22 Mean C-centre durations in C#CV, C#CCV, and CC#CV sequences at normal and fast speech rates across all speakers

This pattern is also exhibited in the individual productions of all speakers (figure 5.23). All ten speakers exhibit a similarity between the duration and coordination pattern of the SI cluster in the C#CC sequence and that in the CC#C sequence where it is hypothesized that SF C2 migrates to form a SI cluster. Please refer to appendix B for detailed results for individual speakers.

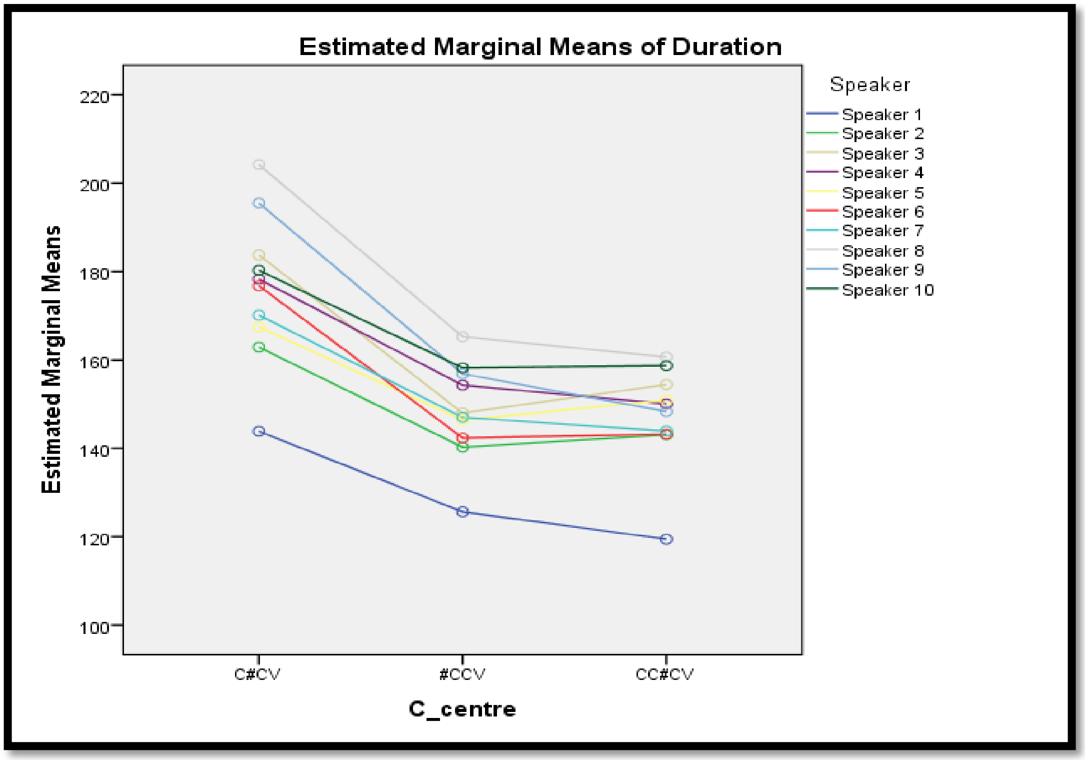


Figure 5.23 Mean C-centre durations in **C#CV**, C#**CCV**, and C**C#CV** sequences at normal speech rates for each speaker

5.3.2.3.3 Statistical analysis

A one-way ANOVA statistical test was performed to compare the C-centre means in the three sequences at both normal and fast speech rates. A Bonferroni Post Hoc statistical test was used to check for specific significant differences between the mean C-centres of the three sequence types compared. The hypothesis that SF C2 of the CC#C sequence migrates to the other side of the word boundary in a resyllabification process resulting in similar syllable structure to the C#CC sequence will be supported if no significant difference with an alpha value of $p>0.05$ is found between the C-centre in the C**C#CV** sequence and the baseline C#**CCV** sequence.

At normal speech, the one way ANOVA showed that there was significant difference with a value of $p<0.05$ between the means. The Bonferroni Post Hoc test (table 5.31) demonstrates that a significant difference value of $p<0.05$ was observed between the C-centre durations in the baseline C#**CCV** and the **C#C**V sequence. The same significant difference value $p<0.05$ was also observed between the C**C#CV** sequence under investigation and the **C#CV** sequence.

(I) Sequence		**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
C#CV	C#**CCV**	27.89*	1.435	.000	24.45	31.33
	C**C#CV**	29.04*	1.435	.000	25.60	32.48
C#**CCV**	**C#CV**	-27.89*	1.435	.000	-31.33	-24.45
	C**C#CV**	1.16	1.435	1.000	-2.29	4.60
C**C#CV**	**C#CV**	-29.04*	1.435	.000	-32.48	-25.60
	C#**CCV**	-1.16	1.435	1.000	-4.60	2.29

*. The mean difference is significant at the 0.05 level.

Table 5.31 Summary of significant effects in the Post Hoc statistical analysis of C-centre in C#CV, C#CCV, and CC#CV sequences across all speakers normal speech rate

However, in support of the coda C2 migration hypothesis, the Bonferroni Post Hoc test shows that there was no significant difference between the mean C-centre durations in the C**C#CV** sequence and baseline C#**CCV** sequence where a significance value of $p=1.000$ was observed. This shows that the durational and gestural coordination pattern between stops of the SI cluster in the baseline C#**CCV** sequence and the following vowel offset are identical to the durational and gestural coordination pattern between stops in the C**C#CV** sequence and the following vowel offset. In further support of C2 migration hypothesis, the same pattern of significance is also found at the fast speech rate.

The same significance pattern between these mean was also found in the individual speaker productions when the one-way ANOVA was run for the productions of each speaker. Results show that all speakers exhibited the same significant differences in C-centre results at both speech rates except for speaker 1 normal and fast speech rates in addition to the fast speech rate of speakers 2. In the case of speaker 1, significant differences were observed between the C-centre durations in all three sequence types at normal speech rate whilst at fast speech rate, no significant differences were found between the C-centre in the baseline C#**CCV** and the C**C#CV** sequences or between the C-centre in the C**C#CV** sequence and the **C#CV** sequences. Speaker 2 exhibited significant differences between the C-centre durations in all three sequence types in fast speech rate.

5.3.2.3.4 Summary

These results have provided proof that tokens of the CC#C sequence undergo a resyllabification or coda migration process whereby the SF C2 of the CC#C sequence delinks and bonds with the SI singleton adjacent to the word boundary. Evidence of this was found in the ICI distribution and durations occurring between stops in both the CC#C and C#CC sequences where a similar pattern is observed in sections 5.3.2.2 and 5.3.2.3 of this chapter and sections 4.3.2.2 and 4.3.2.3 of the EPG data investigating the CC#C and C#CC sequences.

As a result, the phonological and syntactic boundaries are not aligned in the CC#C sequence. The phonological boundary is actually within the SF cluster whereas the syntactic boundary is at the word boundary. In support of the hypothesis, the syllabic configuration in the CC#C sequence undergoes an alternation process resulting in a syllabic configuration identical to the C#CC sequence due to the migration of the SF C2 coda in the CC#C sequence to the adjacent side of the boundary and thus resulting in both sequences exhibiting an identical gestural coordination and ICI distribution pattern.

5.3.2.4 ICI duration and distribution in four-stop CC#CC sequence

Consisting of four stops, this sequence has the greatest possible positions for the occurrence of ICIs. These are within the SF cluster, across the word boundary, and within the SI cluster.

As previously noted (section 5.3.1.4), the percentage of unmasked releases occurring between stops in this sequence is very high occurring in 97% of tokens in the

SF and SI clusters, and in 90% of tokens across the word boundary. In this four-stop sequence, ICIs may occur within the coda cluster, word boundary, and the onset cluster. Furthermore, it can be anticipated that as seen in the EPG data (section 4.3.2.4), the longest lag durations will occur at the word boundary of this sequence due to the increase of the number of stops and also because both SF and SI clusters in this sequence have the maximum number of stops permissible in the syllabic template of TLA.

Results in table 5.32 illustrate that the distribution and durational pattern of the ICI in this sequence differs from previous sequences investigated. In normal speech rate, lag durations between stops reflected in the resulting ICI are relatively short in both SF and SI positions compared to the ICI duration occurring between stops adjacent to the word boundary. The mean ICI duration between stops of the SF cluster averaged 20ms. The mean ICI duration between stops of the SI cluster was also short averaging 15ms. However, the lag duration between stop gestures spanning the word boundary averaged 51ms. The mean ICI duration between stops of the SF cluster ranged from 13ms to 25ms and between stops of the SI cluster from 10ms to 20ms indicating closer gestural coordination between stops in these positions. On the other hand, the mean ICI duration ranged from 39ms to 68ms between stops adjacent to the word boundary suggesting that gestures spanning the word boundary are pulled apart resulting in longer lag durations.

Normal									
Token	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std. Dev**
wagt#tkasir	19	30	12	53	25	12	11	30	6
wagt#dkar	23	30	14	56	22	11	13	30	6
wagt#ktab	19	30	10	40	30	8	16	30	5
wagt#gdi:m	21	30	8	43	30	7	20	30	6
ʕagd#tkasir	24	30	12	49	21	9	13	30	7
ʕagd#dkar	25	29	13	50	19	4	13	29	7
ʕagd#ktab	23	30	8	39	30	8	17	30	4
ʕagd#gdi:m	23	30	8	43	30	7	19	30	5
hatk#tkasir	22	30	9	44	30	7	11	30	6
hatk#dkar	18	30	9	52	30	4	13	30	9
hatk#ktir	18	30	9	64	25	9	16	30	9
hatk#gdim	18	30	7	61	27	11	17	30	10
fatg#tkasir	16	30	10	49	30	10	10	30	5
fatg#dkar	17	30	8	52	30	8	11	30	7
fatg#ktir	13	30	7	68	27	5	14	30	6
fatg#gdi:m	17	30	5	64	27	7	18	30	6
Mean	**20ms**	**479**	**10**	**51ms**	**433**	**9**	**15ms**	**479**	**7**

Table 5.32 Mean ICI durations at SF, word boundary, and SI position in CC#CC sequence at normal speech rate

This gestural coordination pattern is exhibited throughout all tokens. In /wagt#gdi:m/, the mean ICI duration between stops in SF position was 21ms and 20ms between stops of the SI position. These relatively short ICIs indicate that stop gestures are tightly coordinated in these positions. The mean lag duration found across the word boundary in this example was 43ms which is double the lag durations in the SF and SI clusters. This indicates that gestural coordination across the word boundary is relatively weak and the TT gesture is pulled away from the TB gesture. This gestural coordination pattern is further highlighted by the ICI durations in /wagt#dkar/ in figure 5.24.

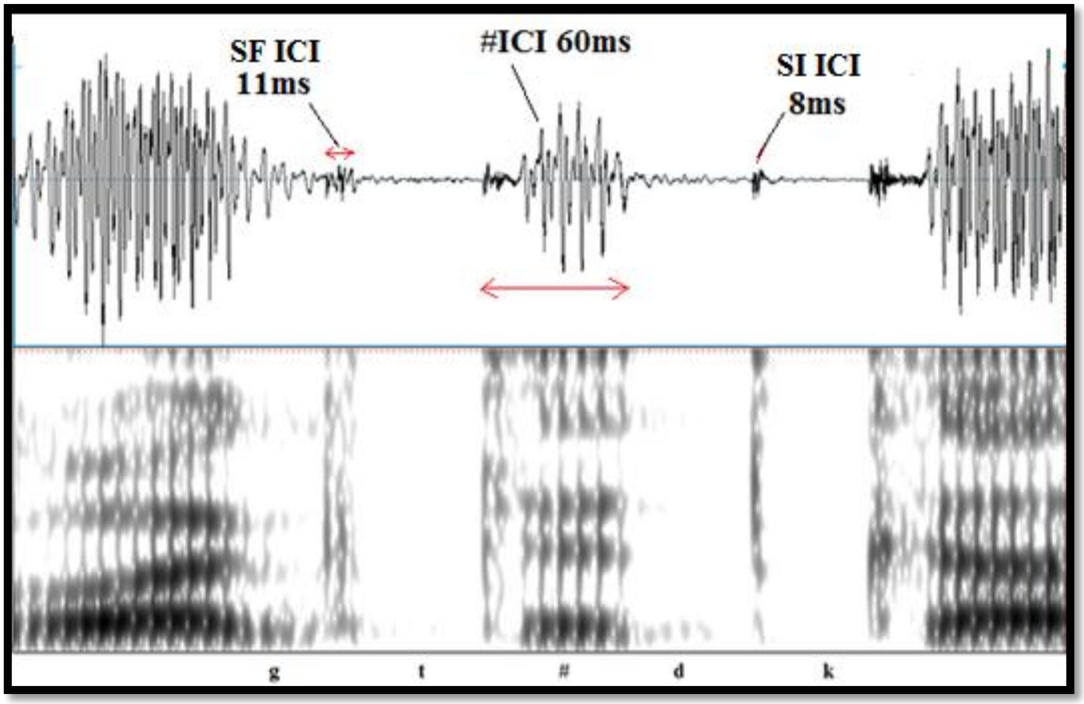


Figure 5.24 SF ICI, #ICI, and SI ICI in /wagt#dkar/ at normal speech rate

The shortest mean lag duration across the word boundary is found between the TT /t/ and TB /k/ in /ʕagd#ktab/. Here the mean ICI duration was 39ms. However, in line with the general pattern, stop gestures of both the SF and SI clusters exhibited tighter gestural coordination with the mean ICI duration averaging 23ms in SF position and 17ms in SI position. As opposed to tokens of the C#CC and C#CC sequences previously investigated where long lag durations were found between C1 and C2 of tokens of both sequences, the long lag duration in tokens of this sequence were found between C2 and C3 of the sequence.

The short lag durations exhibited in SF and SI positions of the CC#CC sequence are similar to the lag durations exhibited across the word boundary of tokens of the C#C sequence (section 5.3.2.1) and in the SI cluster of the C#CC sequence (section 5.3.2.2). On the other hand, the lag durations found in the SF cluster of the CC#CC sequence differ from those occurring in the SF cluster of the CC#C sequence in section 5.3.2.3. However, previous results (section 5.3.2.3.1) reveal that SF C2 of the CC#C sequence is actually SI C1 as a result of the resyllabification process occurring in the CC#C sequence. This also provides evidence that SF C2 of the CC#CC sequence does not migrate here.

It is worth noting that the results also indicate that lag durations across the word were longest where stops adjacent to the word boundary are homorganic stops. In tokens where TT gesture is followed by another TT gesture and a TB gesture is followed by a TB gesture, mean ICI durations were relatively longer in duration compared to when a TT gesture is followed by a TB gesture or vice versa. When the homorganic stops both consist of a TB gesture (as in /hatk#ktir/, /hatk#gdi:m/, /fatg#ktir/, /fatg#gdi:m/), the mean lag durations ranged from 61ms and 68ms. On the other hand, when a TB gesture is followed by a TT gesture, the mean lag duration ranged from 44ms to 52ms. Similarly, when the stops consist of TT gestures (as in /wagt#tkasir/, /wagt#dkar/, /ʕagd#tkasir/, /ʕagd#dkar/), the mean lag durations ranged from 49ms to 56ms. Whereas when the stops adjacent to the word boundary consist of a TT gesture followed by a TB gesture, the mean lag durations ranged from 39ms to 43ms.

In general, the ICI distribution and duration pattern between stops of the CC#CC sequence is characterized by a tight gestural coordination between stops in the SF and SI clusters. However, weak gestural coordination resulting in long ICI durations occurs across the word boundary. This pattern is exhibited by all the speakers. However, the degree of gestural coordination varied in some speakers as presented in table 5.33. The mean ICI duration across all tokens in SF position was 32ms in the productions of speaker 7. This indicates a slightly weaker gestural coordination pattern than the one exhibited by the other speakers. This is also the case in SI position where a mean ICI duration across all tokens averaging 25ms is found which is also relatively longer than other speakers.

Normal									
Speaker	**Mean SF ICI (ms)**	**N**	**Std Dev**	**Mean # ICI (ms)**	**N**	**Std Dev**	**Mean SI ICI (ms)**	**N**	**Std Dev**
Speaker 1	17	4	7	44	47	11	10	4	5
Speaker 2	27	4	16	45	32	18	14	4	7
Speaker 3	22	4	9	47	33	12	11	4	5
Speaker 4	13	4	4	61	48	12	11	4	5
Speaker 5	19	4	8	53	48	12	12	4	5
Speaker 6	21	4	4	53	48	10	18	4	4
Speaker 7	32	4	9	59	41	20	25	4	7
Speaker 8	14	4	5	54	48	14	12	4	6
Speaker 9	9	4	3	42	40	17	12	4	7
Speaker 10	21	4	5	54	48	8	20	4	6

Table 5.33 Mean SF ICI, # ICI, and SI ICI in CC#CC sequence across all tokens at normal speech rate

As for the increase in speech rate, in fast speech rate the same gestural coordination pattern is also exhibited between stops of the CC#CC sequence tokens. SF and SI clusters both exhibit relatively short lag durations in an indication of tighter gestural coordination. However, stop gestures adjacent to the word boundary exhibit longer ICI durations between them indicating that gestures in this position are further pulled apart resulting in weak gestural coordination. However, it is worth noting that the increase in speech rate did not have an effect on the lag durations occurring in the SF and SI positions where they remained almost stable at both speech rates. On the other hand, the increase in speech rate did result in a decrease in the mean ICI duration occurring across the word boundary suggesting that the increase in speech rate resulted in stop gestures being more closely coordinated as the mean ICIs in table 5.34 reveal. Please refer to Appendix A for the fast speech rate of individual speakers.

Fast									
Token	**Mean SF ICI**	**N**	**Std Dev**	**Mean # ICI**	**N**	**Std Dev**	**Mean SI ICI**	**N**	**Std. Dev**
wagt#tkasir	17	30	9	52	21	10	10	30	6
wagt#dkar	18	28	9	50	24	9	10	30	6
wagt#ktab	16	30	7	33	30	10	14	30	4
wagt#gdi:m	17	30	7	38	30	9	16	30	5
ʕagd#tkasir	17	28	7	44	24	11	9	30	5
ʕagd#dkar	17	29	10	47	24	6	11	30	4
ʕagd#ktab	18	29	11	34	30	12	15	28	6
ʕagd#gdi:m	16	29	7	35	30	7	16	30	6
hatk#tkasir	19	30	7	39	30	14	8	30	5
hatk#dkar	19	30	9	43	30	15	11	29	6
hatk#ktir	18	30	8	58	27	9	16	28	8
hatk#gdim	17	30	7	62	27	9	14	30	7
fatg#tkasir	17	30	9	47	30	11	9	30	5
fatg#dkar	16	30	4	47	30	12	11	30	4
fatg#ktir	16	30	8	59	24	14	16	30	5
fatg#gdi:m	16	30	8	53	27	14	15	28	6
Mean	**17ms**	**473**	**8**	**43ms**	**438**	**12**	**13ms**	**473**	**6**

Table 5.34 Mean ICI durations at SF, word boundary, and SI position in CC#C sequence at fast speech rate

5.3.2.5 Summary

The results of the distribution and duration of ICIs in the four sequence types are consistent with the EPG data results in section 4.3.2. Tokens of the C#C sequence exhibited the shortest lag durations between stops adjacent to the word boundary. This is due to the fact that the number of stops in the sequence does not violate the syllabic template of TLA. At both speech rates, gestural coordination between stops of this sequence were closely coordinated resulting in short ICIs averaging 14ms across all tokens.

As for the tokens of the other sequences where the number of stops violate the syllabic template of TLA, a different gestural coordination pattern emerged. In the C#CC sequence, long lag durations averaging 47ms in normal speech rate and 37ms in fast speech rate across all tokens occurred across the word boundary indicating weak gestural coordination. In SI position, lag durations were significantly shorter averaging 16ms in normal speech rate and 15ms in fast speech rate across all tokens indicating tighter gestural coordination between stops in this position.

In the CC#C sequence, an interesting result that is found is that this sequence undergoes a resyllabification process where SF C2 migrates to the other side of the word boundary as highlighted by the previous results (section 5.3.2.3.1). The resulting configuration is similar to the syllabic configuration of the C#CC sequence as a result of the weak gestural coordination pattern and therefore a longer ICI duration occurring between stops of the SF cluster of the **CC**#C sequence. As a result, both the CC#C and C#CC sequences are phonologically the same exhibiting the same gestural coordination patterns between their stops. Here the mean ICI occurring between C1 and C2 averaged 43ms in normal and 29ms in fast speech rates. As for the mean ICI duration between C2 and C3 this averaged 15ms in normal and 14ms in fast speech rate. This can be highlighted by the similarity in ICI distribution and duration in /ʃad#ktir/ of the C#CC sequence and /ʕagd#kam/ of the CC#C sequence in figures 5.25 and 5.26.

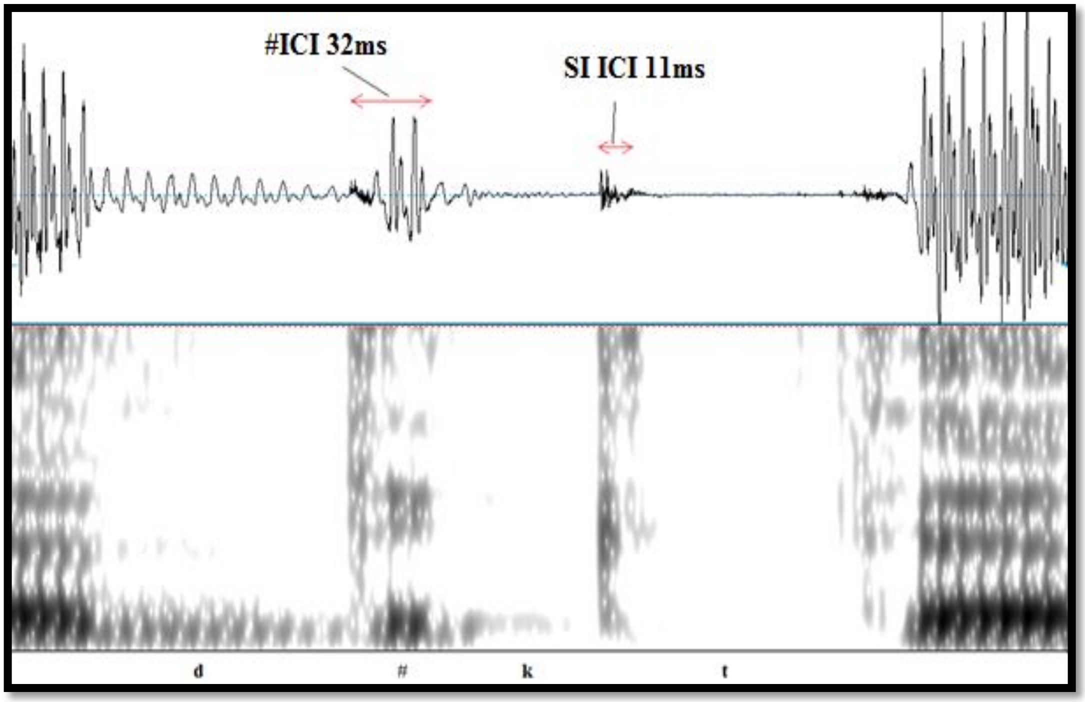


Figure 5.25#ICI and SI ICI in /ʃad#ktir/ at normal speech rate

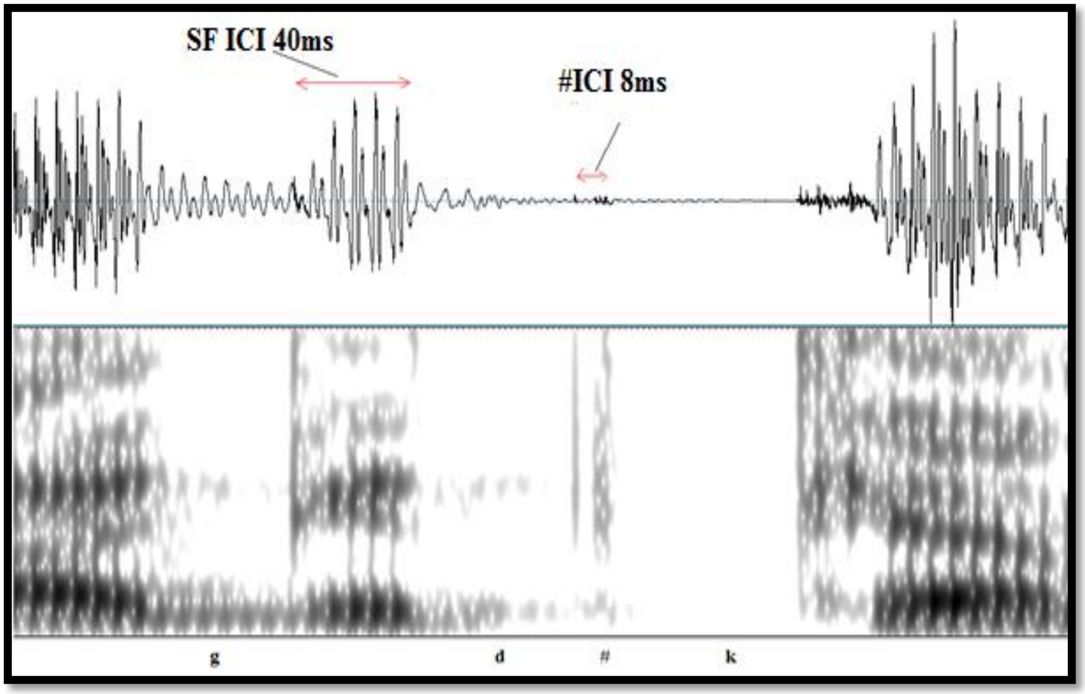


Figure 5.26 SF ICI and #ICI in /ʕagd#kam/ at normal speech rate

As for the CC#CC sequence, stops of the SF and SI clusters exhibited closer gestural coordination reflected in the short lag duration of 20ms and 15ms respectively in normal speech rate and 17ms and 13ms respectively in fast speech rate. Stop gestures in both these positions are closely coordinated. However, weak gestural coordination is exhibited across the word boundary where the mean ICI duration across all tokens in this position averaged 51ms in normal and 43ms in fast speech rate. The short lag occurring in the SF cluster of the CC#CC sequence is also an indication that the syllabic structure in this sequence is stable as opposed to the CC#C sequence.

It is also worth noting that lag durations between homorganic stop sequences tended to be longer than the lag durations occurring between heterorganic stop sequences. This is found in long ICI durations typical of epenthetic vowels across the word boundaries of the C#CC and CC#CC sequences where it was possible to control the place of articulation of stops adjacent to the word boundary resulting in both homorganic and heterorganic sequences. When a TT gesture is followed by another TT gesture or a TB gesture is followed by another TB gesture, lag durations were found to be longer than opposing place of articulation stops.

An interesting finding is that the increase in speech rate did not result in a change in the distribution pattern of ICIs. However, the increase in speech rate resulted in closer gestural coordination indicated by the decrease in the ICI durations in positions that exhibited long lag durations. These are the word boundary of the C#CC sequence, the phonological word boundary of the CC#C sequence, and the word boundary of the CC#CC sequence. All ICIs occurring in this position exhibited a decrease in their duration and therefore closer gestural coordination as a result of the increase in speech rate. On the other hand, ICIs occurring in positions that exhibited short lag durations, such as the word boundary of the C#C sequence, the SI cluster of the C#CC sequence, the syntactic word boundary of the CC#C sequence, and both SF and SI clusters of the CC#CC sequence, these ICIs were not affected by the increase in speech rate.

It can be concluded that two distinct types of ICIs emerge in line with results of the EPG data. The first is a long ICI occurring where long lag is found between stop gestures. This type is typical of epenthetic vowel durations that occur in positions where gestural coordination is at its weakest as identified above. The second is a short ICI occurring where short lag is found between stop gestures. This type of ICI occurs in positions where closer gestural coordination between stop gestures was exhibited. The second type does not seem to be a true epenthetic vowel but has durations typical to "excrescent" vowels that are a result of the transition process between consonant articulations (Hall 2011). The following section presents the results of an investigation into whether these ICIs do actually belong to two distinct groups in terms of their durations and how the voicing of adjacent segments affects the voicing of both these types of vowels in an attempt to answer research question 4 to find out whether the epenthetic vs. excrescent vowel distinction is valid in TLA.

5.3.3 Nature of ICIs; "epenthetic" vs. "excrescent"

The ICI durations and distributional patterns discussed in this chapter (section 5.3.2) and in the EPG data results (section 4.3.2), clearly show a bimodal distribution of ICIs in which shorter ICIs are typical of excrescent vowels and longer ICIs are typical of epenthetic vowels. This section presents the results of the classification of both types of ICIs. The first section compares between the mean durations of the two types of ICIs in order to find out if they belong to distinct categories in terms of their durations. Furthermore, in order to confirm that they belong to two distinct groups, statistical tests are carried out to see whether the differences between the means of both groups are significant and therefore confirming that the epenthetic/excrescent vowel distinction (Hall 2013) is valid in TLA.

The following section analyses how the voice qualities of these ICIs are affected by the voicing context of adjacent segments. The voicing of these ICIs are examined in the four different voice contexts of adjacent segments:

- Voiceless + voiceless
- Voiced + voiced
- Voiceless + voiced
- Voiced + voiceless

Due to the large amount of data, the excrescent vowels occurring in two of the five of the positions where excrescent vowels are found were used for this investigation; those occurring at the word boundaries in tokens of the C#C and CC#C sequences. In addition, epenthetic vowels occurring in two out of three of the positions where epenthetic vowel positions are found were used; those occurring at the word boundaries of the C#CC and CC#CC sequences. Taking into account any voice assimilation processes, the phonological voicing of the adjacent segments was taken into consideration in this investigation.

5.3.3.1 Durations of “epenthetic” and “excrescent” vowels

Table 5.35 presents the results of the mean duration of ICIs occurring between stops of the C#C, C#CC, CC#C, and CC#CC sequences across all tokens. The results indicate that ICIs occurring in different positions in these sequences differ in terms of their durations. At both normal and fast speech rates, two patterns of ICIs emerge in terms of the duration of the ICIs. In the excrescent vowel positions (positions 1-5); the mean duration of the vowel ranged from 14ms to 20ms at normal speech rate and from 12ms to 17ms at fast speech rate. These positions exhibited closer gestural coordination between their stops (sections 4.3.2 and 5.3.2). In the epenthetic vowel positions (positions 6-8); the mean duration of the vowel ranged from 43ms to 51ms in normal speech rate. In fast speech rate, the range decreased to 29ms to 46ms.

ICI position	**Normal**			**Fast**		
	Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
(1) # of C**#**C	14	237	8	14	233	8
(2) # of CC**#**C	15	239	9	14	234	7
(3) SI of C#**CC**	16	480	7	15	474	6
(4) SF of **CC**#CC	20	479	10	17	473	8
(5) SI of CC#**CC**	15	479	7	13	473	6
(6) SF of **CC**#C	43	480	9	29	480	7
(7) # of C**#**CC	47	439	14	37	389	13
(8) # of CC**#**CC	51	433	9	43	438	12

Table 5.35 Mean ICI durations occurring between stops in the four sequence types across all tokens

Furthermore, the mean duration of all instances of excrescent vowels in normal speech rate averaged 16ms and 14ms in fast speech rate. Epenthetic vowels on the other hand were considerably longer. The mean duration of all instances of epenthetic vowels averaged 47ms at normal speech rate and 37ms in fast speech rate. Based on these durational results, ICIs typical of excrescent vowels occur in the following positions:

1- The word boundary of the C**#**C sequence.
2- The word boundary of the CC**#**C sequence.
3- SI cluster of the C#**CC** sequence.
4- SF cluster of the **CC**#CC sequence.
5- SI cluster of the CC#**CC** sequence.

On the other hand, longer ICIs typical of epenthetic vowels occur in the following three positions:

6- SF cluster of the **CC**#C sequence.
7- The word boundary of the C**#**CC sequence.
8- The word boundary of the CC**#**CC sequence.

Another interesting observation is that the increase in speech rate has a different effect on each type of vowel. In the case of epenthetic vowels, the increase in speech rate resulted in a decrease in the duration and therefore an increase in the degree of gestural coordination between stops. On the other hand, excrescent vowels are not affected by the increase in speech rate. Their durations remain stable at both normal and fast speech rates. This distinction between excrescent and epenthetic vowels in terms of duration also applies to both normal and fast speech rates as highlighted in figure 5.27. All ten speakers exhibited this distinction in their individual productions.

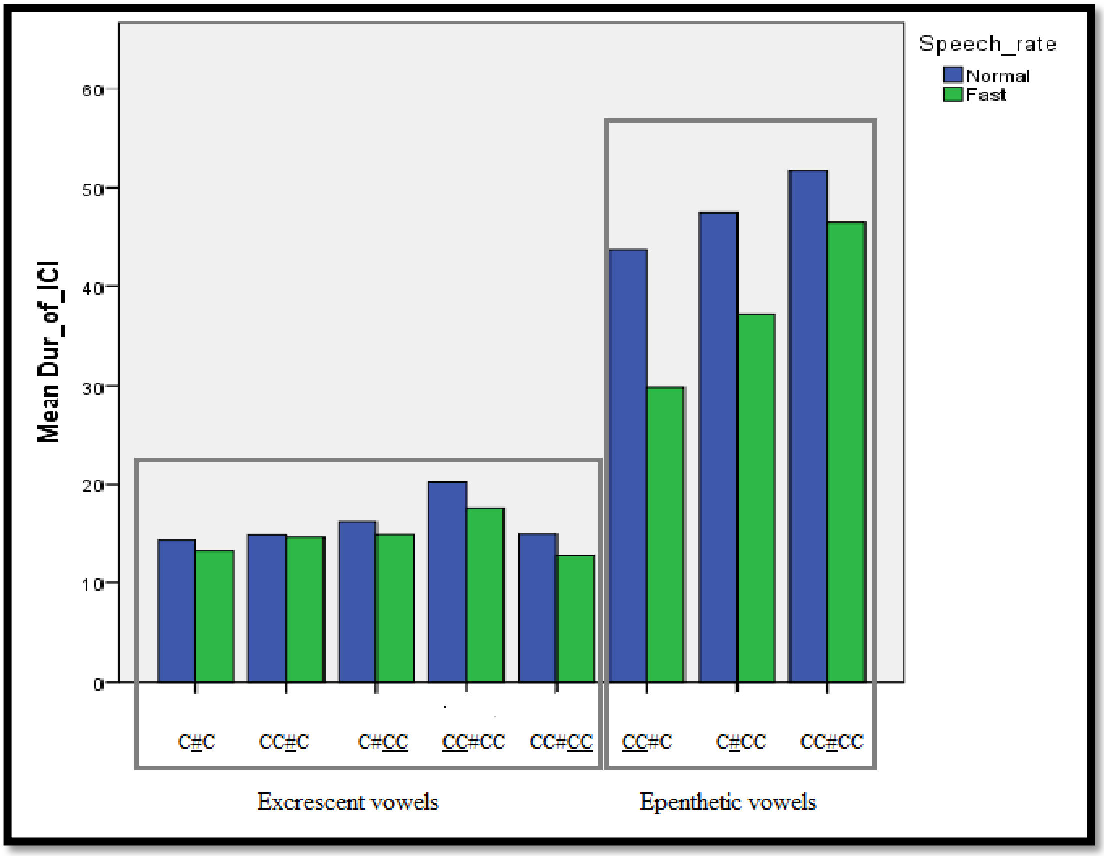


Figure 5.27 Durational pattern of excrescent and epenthetic vowels for both speech rates. The location of the ICI is underlined in each position

5.3.3.2 Statistical analysis

In order to verify that excrescent and epenthetic vowels in the data belong to two distinct categories in terms of their duration, a significance test was conducted to determine if statistically significant difference between the total durations of both types of vowels exist. The conclusion that the vowels belong to two distinct groups in terms of their durations is supported if a significant difference of $p<0.05$ is found between the two categories. The normality tests show that the data was not normally distributed with the Shapiro-Wilk showing an alpha value of $p<0.05$. Therefore a Mann-Whitney U non-parametric test was conducted to test for significant differences between their durations.

At normal speech rate, a statistically significant difference between the duration of excrescent and epenthetic vowels was found with a value of $p < 0.05$. Results of the significance test for each speaker individually at normal speech rate also reveal that the same significant difference between the excrescent and epenthetic vowels with an alpha value of $p<0.05$ was found in the productions of all ten speakers.

Normality test of the durations of both types of vowels also revealed that the fast speech rate exhibited a non-normal distribution with an alpha value of $p<0.05$. The Mann-Whitney U non-parametric test shows that a statistically significant difference between the durations of excrescent and epenthetic vowels with a value of $p <0.05$ is exhibited by the fast speech rate. As for the productions of individual speakers, a significant difference with a value of $p<0.05$ was also found between the durations of the excrescent and epenthetic vowels in the individual productions of the ten speakers, as noted previousy at normal speech rate.

5.3.3.3 Voicing of epenthetic and excrescent vowels

Results show that the relationship between the voice value of epenthetic and excrescent vowels and the voice context of adjacent segments differed. The voicing of epenthetic vowels was not greatly affected by the voicing context of adjacent segments. Epenthetic vowels appear to be independent in terms of their voicing, being unaffected by the voicing of neighbouring stops. Epenthetic vowels occurred mostly voiced. These were 100% voiced at both normal and fast speech rates in the +V+V voice context. The independence of the epenthetic vowels was particularly evident in the -V-V context. Although both adjacent segments occurred voiceless, in normal speech rate 77.5% of the epenthetic vowels occurring in this voicing context were voiced and only 80 instances of a total of 356 in this voice context occurring voiceless. This is illustrated in figure 5.28 where a voiced epenthetic vowel occurs between two voiceless TT gestures in /wagt#tkasir/. In fast speech rate, the percentage of voiced epenthetic vowels decreased slightly to 64.5% but still remained considerably higher than voiceless epenthetic vowels.

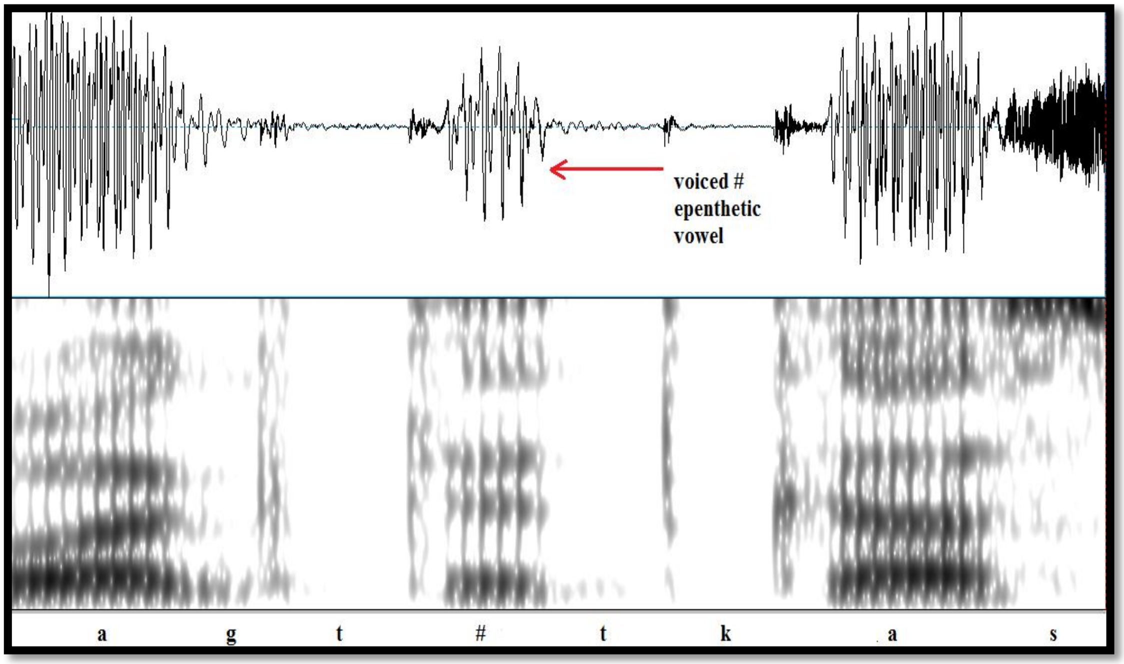


Figure 5.28 Voiced epenthetic vowel in -V-V context at the word boundary of /wagt#tkasir/ of the CC#CC sequence in normal speech rate

In the two remaining voice –V+V and +V-V voice contexts, the percentage of epenthetic vowels occurring as voiced was 93% and 97% respectively in normal speech rate and 96% and 93% respectively in fast speech rate. This highlights the minimal effect of the voicing of adjacent segments on that of epenthetic vowels, exhibiting their degree of independence in terms of voicing. The voicing of epenthetic vowels is further illustrated in figure 5.29.

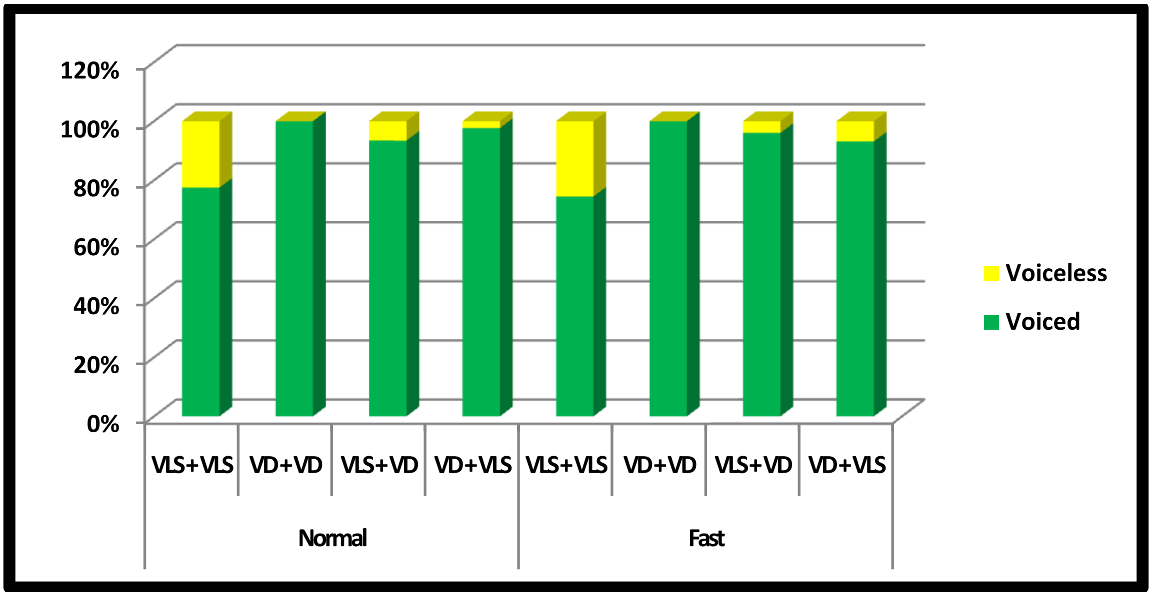


Figure 5.29 Voicing of epenthetic vowels in different voicing contexts in normal and fast speech rates showing a high percentage of epenthetic vowels occurring as voiced across all contexts

Excrescent vowels behaved differently in terms of voicing. Unlike the independence exhibited by epenthetic vowels, excrescent vowels appear to be more influenced by and therefore more dependent on the voicing context of the adjacent segments. As opposed to epenthetic vowels where only 23% occurred as voiceless in the -V-V context, the percentage of excrescent vowels occurring voiceless in the -V-V context is 99% at normal speech rate and 100% at fast speech rate (figure 5.30).

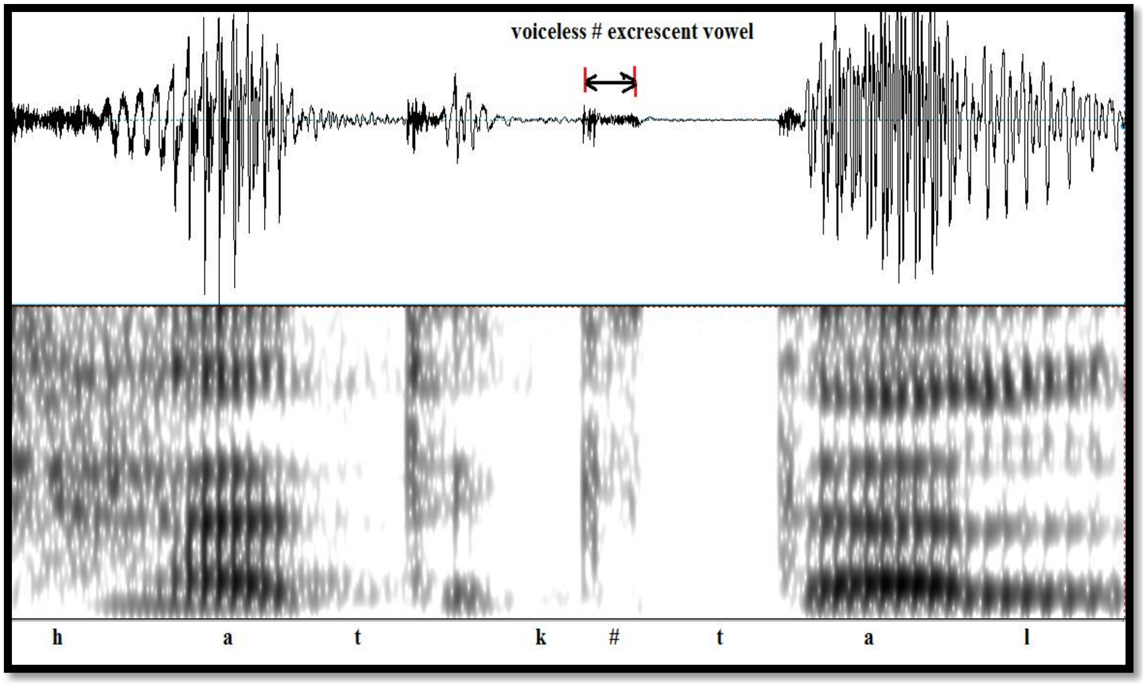


Figure 5.30 Voiceless excrescent vowel in a -V-V context occurring at the word boundary of /hatk#tal/ of the CC#C sequence

Furthermore, 96% of excrescent vowels occurring in the +V+V context are voiced at both normal and fast speech rates (figure 5.31). This highlights the fact that the voicing of excrescent vowels is more dependent on the voicing of adjacent stops and is therefore affected by their voice values.

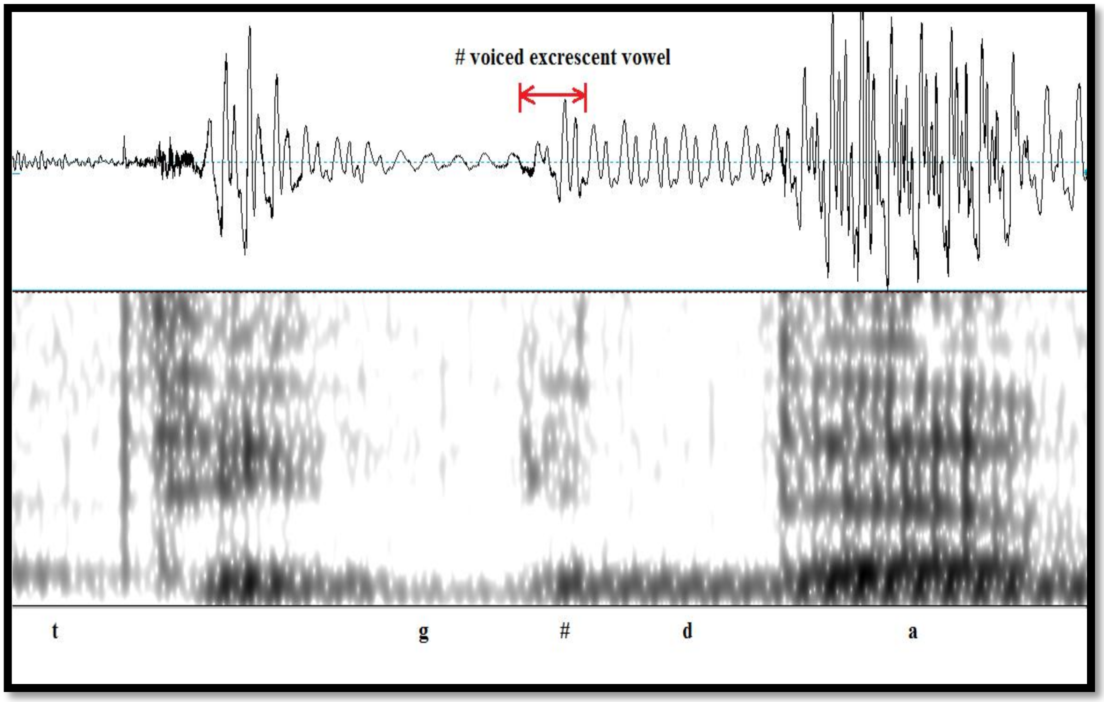


Figure 5.31 Voiced excrescent vowel in a +V+V context occurring at the word boundary of /fatg#dam/ of the CC#C sequence

Excrescent vowels in the -V+V contexts were voiceless in 54 out of a total of 56 instances, a percentage of 96% at normal speech rate. At the fast speech rate, the percentage excrescent vowels occurring as voiceless decreased to 81%. Finally in the +V-V context, at both speech rates the ratio of voiced to voiceless excrescent vowels was almost equal. At normal speech rate the percentage of voiceless excrescent vowels increased to 55% and 57% at fast speech rate. The variability in the voice value of excrescent vowels in opposing voice contexts further highlights the difference between these types of vowels and epenthetic vowels. Unike excrescent vowels, the voice value of epenthetic vowels remained almost stable being mostly voiced in both opposing voice contexts. The variability of the voicing of excrescent vowels in different voice contexts is further highlighted in figure 5.32.

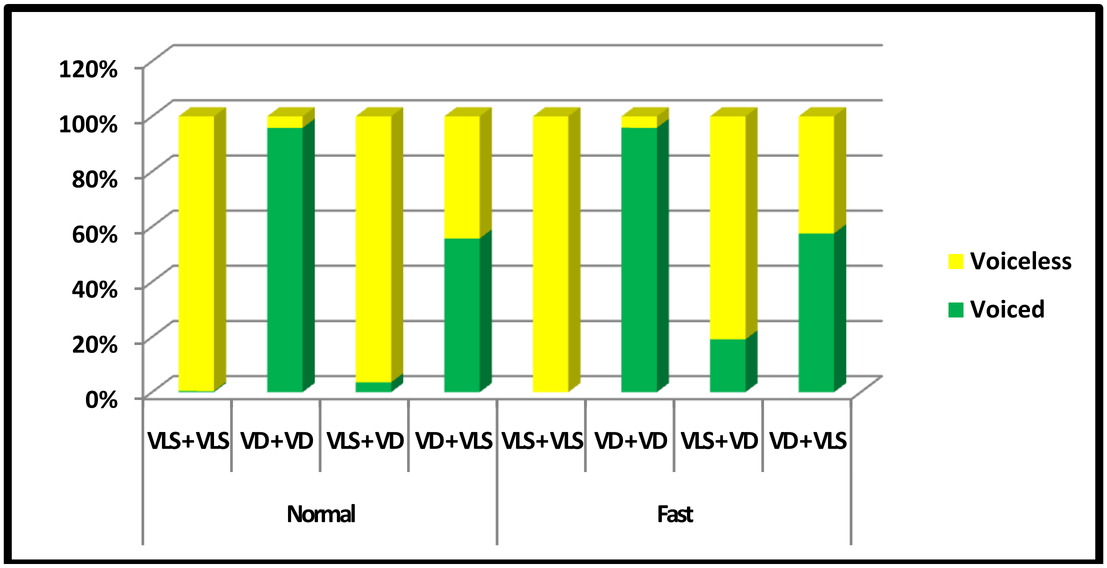


Figure 5.32 Voicing of excrescent vowels in different voicing contexts in normal and fast speech rates

5.3.3.4 Summary

The results confirm that two distinct types of ICIs occur between stops resulting from the lack of unmasked stop releases. The first type is true epenthetic vowels that are characterized by their longer durations and independent voice quality. It can be argued that epenthetic vowels are specified as voiced but are sometimes devoiced in -V-V contexts. They are found to occur between stops adjacent to the word boundary in tokens of the C#CC and CC#CC sequence where gestural cohesion is very weak. They are also found occurring between stops of the SF cluster in tokens of the CC#C sequence. However, as highlighted by previous results (section 5.3.2.3.2), this is actually a phonological word boundary. Epenthetic vowels are also affected by the increase in speech rate. At fast speech rate, they exhibit a decrease in their duration resulting in closer gestural coordination between stops.

The second type is excrescent vowels that are shorter in duration and their voice qualities exhibit more variation depending on the voice context in which they occur. They are not specified as voiced but become voiced next to voiced consonants. Due to their short durations, they occur between stops that are more cohesive in terms of their gestural coordination pattern. Excrescent vowels occur at the word boundary in tokens of of the C#C sequence. They are also found between SF and SI stops in tokens of the CC#CC sequence and between SI stops in tokens of the C#CC sequence. In tokens of the CC#C sequence, they are found to occur at the word boundary. However, in this position they actually occur between stops of a phonological SI cluster as a result of the coda migration process previously detailed (section 5.3.2.3.2). Excrescent vowels are not affected by the increase in speech rate and unlike epenthetic vowels they do not exhibit a considerable decrease in their duration as exhibited by epenthetic vowels.

5.4 The influence of the order of place of articulation on gestural coordination

This section presents the results of the acoustic data on the effect the order of place of articulation of adjacent stops on gestural coordination across the word boundary. EPG data results (section 4.4) revealed that gestural coordination in the coronal-dorsal (CD) order of articulation of stops spanning the word boundary in the C#C sequence is more cohesive and closer than its dorsal-coronal (DC) counterpart. The acoustic data was also classified as CD or DC according to the order of place of articulation of the stops across the word boundary. The degree of gestural coordination across the word boundary is identified in terms of the lag durations between the release of the HP of C1 to the onset of closure of the following C2. The resulting ICIs, in this case excrescent vowels, in both orders of articulation are compared to determine if a similar effect on gestural coordination exists to that described in the EPG data (section 4.4). Likewise, in order to avoid any coarticulatory effects from tautosyllabic stops on the production of consonants adjacent to the word boundary, the CC#C, C#CC, and CC#CC sequences were excluded from this investigation since coarticulation affects their coproduction. The main focus is on tokens of the two-stop sequence C#C where no coarticulatory effects from neighbouring consonants can influence the degree of gestural coordination across the word boundary between the stops under investigation.

Homorganic sequences were excluded from this investigation since the order of place of articulation is the same as in the tokens /ʒit#tal/, /dag#kif/, /ʃid#dis/ etc. (see table 4.32 for a full list of tokens investigated for each order of place of articulation).

5.4.1 Influence of order of place of articulation on gestural coordination in C#C sequence

The percentage of unmasked stop releases for each order of place of articulation is presented first in table 5.36. As previously seen (section 5.3.1), unmasked stop releases occurred in almost all tokens of the four sequence types including the C#C sequence. The only exception where stop closure overlap occurred was in homorganic sequences that are not investigated here. The results show that most tokens exhibit unmasked stop releases in both the CD and DC place order of articulation. This result is not consistent with the results of the EPG data. However, as previously discussed, these unmasked releases do not necessarily indicate weak gestural coordination.

		Normal			**Fast**		
	Token	**# rls.**	**% rls.**	**N**	**# rls.**	**% rls.**	**N**
CD	ʒit#kalb	30	100	30	30	100	30
	ʒit#giʃ	29	96	30	30	100	30
	ʃid#kif	30	100	30	30	100	30
	ʃid#giʃ	29	96	30	26	96	30
	Total	**118**	**98%**	**120**	**116**	**96%**	**120**
DC	fak#tal	30	100	30	29	96	30
	fak#dam	29	96	30	30	100	30
	dag#tal	30	100	30	29	96	30
	dag#dam	30	100	30	29	96	30
	Total	**119**	**99%**	**120**	**117**	**97%**	**120**

Table 5.36 Unmasked release percentages of SF stop in C#C sequence in CD and DC order of place of articulation

Despite the lack of difference between the CD and DC order of place of articulation presented above, the lag durations for each context differ. Table 5.37 presents the results of the mean ICI duration occurring in tokens of the CD and DC order of place of articulation. In the CD context, the mean ICI occurring between the release of C1 and onset of HP of C2 was 10ms in normal speech rate and 8ms in fast speech rate. In the DC context, the mean ICI duration increased relatively. In this order of place of articulation, the mean ICI duration was 19ms in normal speech rate and remained stable in fast speech rate. These results indicate that gestural coordination varies with more cohesive gestural coordination exhibited by tokens of the CD order of place of articulation.

Token		**Normal**			**Fast**		
		Mean (ms)	**N**	**Std. Dev.**	**Mean (ms)**	**N**	**Std. Dev.**
CD	ʒit#kalb	10	30	5	8	30	3
	ʒit#giʃ	9	29	5	8	30	4
	ʃid#kif	11	30	5	11	30	6
	ʃid#giʃ	9	29	7	7	26	5
	Mean	**10ms**	**118**	**6**	**8ms**	**116**	**5**
DC	fak#tal	19	30	6	19	29	6
	fak#dam	18	29	8	19	30	8
	dag#tal	20	30	8	18	29	5
	dag#dam	19	30	7	19	29	6
	Mean	**19ms**	**119**	**7**	**19ms**	**117**	**6**

Table 5.37 Mean word boundary ICI durations for C#C sequence in CD and DC order of place of articulation

In the CD context /ʒit#kalb/ phrase where a TT gesture stop is followed by a TB gesture stop which shares the same voicing, the mean lag duration in normal speech rate was 10ms in normal speech rate. When the same stops occur in the DC context as in the case of /fak#tal/ where a TB gesture stop is followed by a TT gesture stop, the mean lag duration nearly doubled to 19ms. These lag durations indicate that the gestures in both the CD and DC contexts do not exhibit the same degree of gestural coordination. More cohesion is found across the word boundary in tokens of the CD order of place of articulation. This pattern is also evident at fast speech rate where in the CD context token the mean lag duration averaged 8ms and in the DC context token the mean lag duration averaged 19ms.

The pattern is also consistent where both adjacent stops disagree in voicing. At normal speech rate, for /ʒit#giʃ/ where a voiceless TT gesture is followed by a voiced TB gesture in the CD order of place of articulation, the mean lag duration averaged 9ms. When both these stops occur in the DC order of place of articulation as in /dag#tal/, the mean lag duration increased significantly to 20ms. Stop gestures in the DC order of place of articulation are less closely coordinated than in the CD order of place of articulation.

It was previously mentioned (section 5.3.2.5) that lag durations in excrescent vowel positions are not affected by the increase in speech rate. For this reason, the durations of the excrescent vowels occurring in tokens of the C#C in this investigation were not affected by the increase in speech rate and remained stable at both speech rates. Despite this, the same gestural coordination pattern in both orders of place of articulation with more cohesion in the CD than in the DC order of place of articulation is also found between stops in the fast speech rate. These findings are consistent with the findings of the EPG results (section 5.4.1).

5.4.2 Statistical analysis

In order to verify the validity of these results, a significance test was conducted to determine if there is a statistically significant difference between the ICI durations in the CD and DC orders of place of articulation. The conclusion that there is tighter gestural coordination in the CD order of place of articulation than in its counterpart DC is supported if a significant difference of $p<0.05$ is found between the lag durations between stops in both contexts. The normality tests show that the data was not normally distributed with a value of $p<0.05$. In this case, a Mann-Whitney U non-parametric test was conducted to test for significant differences between the excrescent vowels in the CD and DC contexts.

The result of this test indicates a statistically significant difference between the excrescent vowel durations in the CD and DC contexts with a value of $p<0.05$. This suggests that gestural coordination in both orders of place of articulation is significantly different, supporting the assumption that tokens of the CD order exhibit more cohesion between stops adjacent to the word boundary. All speakers exhibited the same results except for speaker 10. In normal speech rate, a significance value of $p=0.109$ and therefore no significant difference was found in this case between lag durations in the CD and DC orders of place of articulation.

The normality test revealed that the fast speech rate exhibited non-normal distribution and therefore the Mann-Whitney U non-parametric test was also applied. A statistically significant difference between the lag durations between stops in the CD and DC orders of place of articulation was found with a value of $p <0.05$. However, at the fast speech rate, no significant difference was found for speakers 6 and 7, with values of $p=0.269$ and $p=0.053$ respectively. Despite this, the general significance pattern at both speech rates confirms that in tokens of the CD order of place of articulation, a more cohesive coordination pattern is exhibited between adjacent stops than in the DC order of place of articulation. These results are in line with the results of the EPG data in section 4.4.1.1.

5.4.3 Summary

The results reveal that the order of place of articulation does have an effect on the degree of gestural coordination across the word boundary in the sequences investigated. These results are in line with the results of the EPG data. In the CD context, the tokens /ʒit#kalb/, /ʒit#giʃ/, /ʃid#kif/, and /ʃid#giʃ/ exhibited closer gestural coordination between the gestures of the stops spanning the word boundary reflected in their relatively short lag durations. This shows that although the release of the stop preceding the word boundary is not completely masked by the closure of the following stop, gestures of both these stops are in-phase with each other resulting in a more cohesive gestural coordination pattern.

On the other hand, in the DC context, for the phrases /fak#tal/, /fak#dam/, /dag#tal/, and /dag#dam/, a decrease in the degree of gestural coordination between gestures of stops spanning the word boundary is found to have a somewhat longer lag duration. In this order of place of articulation, the degree of gestural coordination across the word boundary seemed to decrease with gestures being further pulled apart. The differences between both contexts were further supported by the results of the statistical tests carried out. The results also support the observation that the increase in speech rate does not result in an increase in the degree of gestural coordination in positions where excrescent vowels occur. The excrescent vowel durations occurring at the word boundary of the C#C sequence tokens are stable for both normal and fast speech rates.

5.5 Voice assimilation in C#C sequence

This section attempts to address research question 5 whether voice assimilation occurs across the word boundary in TLA and whether different types of ICIs block this process. This investigation is divided into two sections. The first section presents the results regarding the direction in which voice assimilation occurs across the word boundary in TLA. In order to avoid interference from the occurrence of voice assimilation within SF and SI clusters, this investigation is limited to tokens of the C#C sequence thus excluding the CC#C, C#CC, and CC#CC sequences. The direction of voice assimilation is investigated in –V+V and +V-V voice contexts. Throughout this investigation, stops adjacent to the word boundary are referred to as C1 and C2 where C1 is the SF single articulatory gesture stop and C2 is SI singleton of the C#C sequence. Furthermore, the extent of voice assimilation spreading into the HP of target segments is also examined. The main objective is to investigate how voice assimilation spread is affected by factors such as voice context of adjacent segments, homorganic vs. heterorganic sequences, and speech rate.

The second section focuses on whether excrescent and epenthetic vowels are transparent to voice assimilation or whether they block this process in an attempt to address the second part of the research question. In line with studies by Gafos (2002) and Hall (2006), ICIs occurring at the word boundary of the C#C sequence in TLA were previously identified as excrescent vowels resulting from specific gestural coordination patterns as highlighted by previous results (section 5.3.3). The results also reveal that in homorganic C#C sequences found in /ʒit#dis/, /fak#giʃ/, /ʃid#tal/, and /fak#kif/, tight gestural coordination was exhibited and as a result excrescent vowels were not exhibited at the word boundary due to stop closure overlap. In order to study the effect of voice assimilation on the voice value of excrescent vowels, this investigation was limited to tokens exhibiting unmasked releases resulting in excrescent vowels.

Furthermore, in order to compare the interaction between excrescent and epenthetic vowels and voice assimilation across the word boundary, tokens from the CC#CC sequence were selected and examined for comparative purposes since epenthetic vowels are the type of ICIs occurring at the word boundary of this sequence as previously indicated (section 5.3).

Voicing was examined throughout both stops of the sequence from the onset the HP of C1 to the release of C2 and any intervening ICI. Vocal fold vibration during the HP of C1 and C2 was identified as periodic vibration on the waveform. The data was classified according to the voice values of C1 and C2 of the C#C sequence. This classification resulted in +V-V and a -V+V voice contexts occurring across the word boundary.

5.5.1 Direction of voice assimilation across word boundary

Results indicate that voice assimilation was bi-directional with both regressive and progressive voice assimilation patterns occurring across the word boundary in TLA. However, right-to-left regressive voice assimilation was more frequent. In normal speech rate, 68% of the total number of tokens in which voice assimilation occurred exhibited regressive voice assimilation compared to 32% exhibiting progressive voice assimilation. At fast speech rate, the number of instances of regressive voice assimilation increased to 78% whilst the number of tokens exhibiting progressive voice assimilation decreased correspondingly to 22%.

The results highlight that the voice context of C1C2 plays a role in determining the direction in which voice assimilation occurs. In the +V-V voice context (table 5.38), only regressive right-to-left assimilation of voicelessness was exhibited. In this voice context, C2 is always the trigger and voicing in C1 was always affected and as a result devoiced. Progressive left-to-right voice assimilation was not exhibited in this voice context and C2 always retained its voice value.

Token	**Normal**				**Fast**			
	Reg.	**Prog.**	**No assimilation**	**N**	**Reg.**	**Prog.**	**No assimilation**	**N**
/ʃid#tal/	27	0	3	30	30	0	0	30
/ʃid#kif/	28	0	2	30	27	0	3	30
/dag#tal/	25	0	5	30	16	0	14	30
/dag#kif/	28	0	2	30	20	0	10	30
Total	**108**	**0**	**12**	**120**	**93**	**0**	**27**	**120**

Table 5.38 Direction of voice assimilation (regressive vs. progressive) across the word boundary in tokens of C#C sequence in +V-V voice context

In normal speech rate, regressive assimilation of voicelessness occurred in 100% of the total instances of voice assimilation as illustrated in figure 5.33. Voice assimilation did not occur in 12 tokens. Furthermore, in fast speech rate, regressive assimilation of voicelessness also occurred in all tokens exhibiting voice assimilation. However, the number of tokens not exhibiting voice assimilation increased to 27. The results show that the instances of voice assimilation decreased as a result of the increase in speech rate.

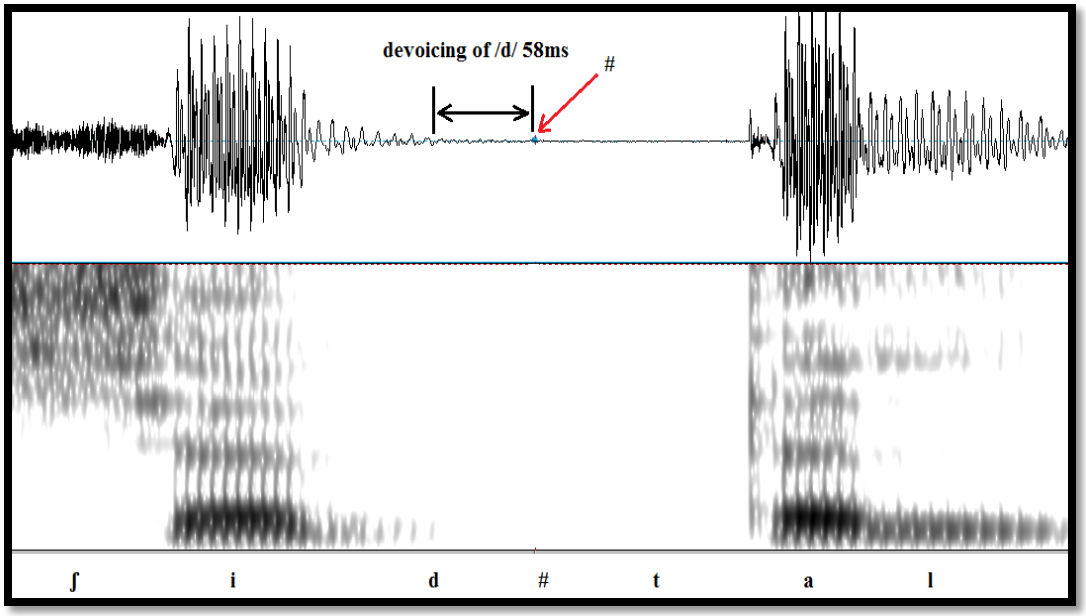


Figure 5.33 Regressive assimilation of voicelessness in +V#-V voice context normal speech rate for /ʃid#tal/ showing partial devoicing of HP of voiced /d/. HP of /d/ =125ms, devoiced duration= 58ms

On the other hand, in the –V#+V voice context the voice assimilation pattern differed. Results in table 5.39 reveal that both regressive and progressive voice assimilation occurs in this voice context. In normal speech rate, progressive assimilation of voicelessness was more frequent than regressive voice assimilation as highlighted in figure 5.34. Progressive assimilation of voicelessness occurred in 69% of the tokens exhibiting voice assimilation.

Token	Normal				Fast			
	Reg.	Prog.	No assimilation	N	Reg.	Prog.	No assimilation	N
/ʒit#dis/	18	8	4	30	27	3	0	30
/ʒit#giʃ/	3	27	0	30	8	15	7	30
/fak#dam/	0	10	20	30	7	14	9	30
/fak#giʃ/	7	20	3	30	17	10	3	30
Total	**28**	**65**	**27**	**120**	**59**	**42**	**19**	**120**

Table 5.39 Direction of voice assimilation across the word boundary in tokens of C#C sequence in -V+V voice context

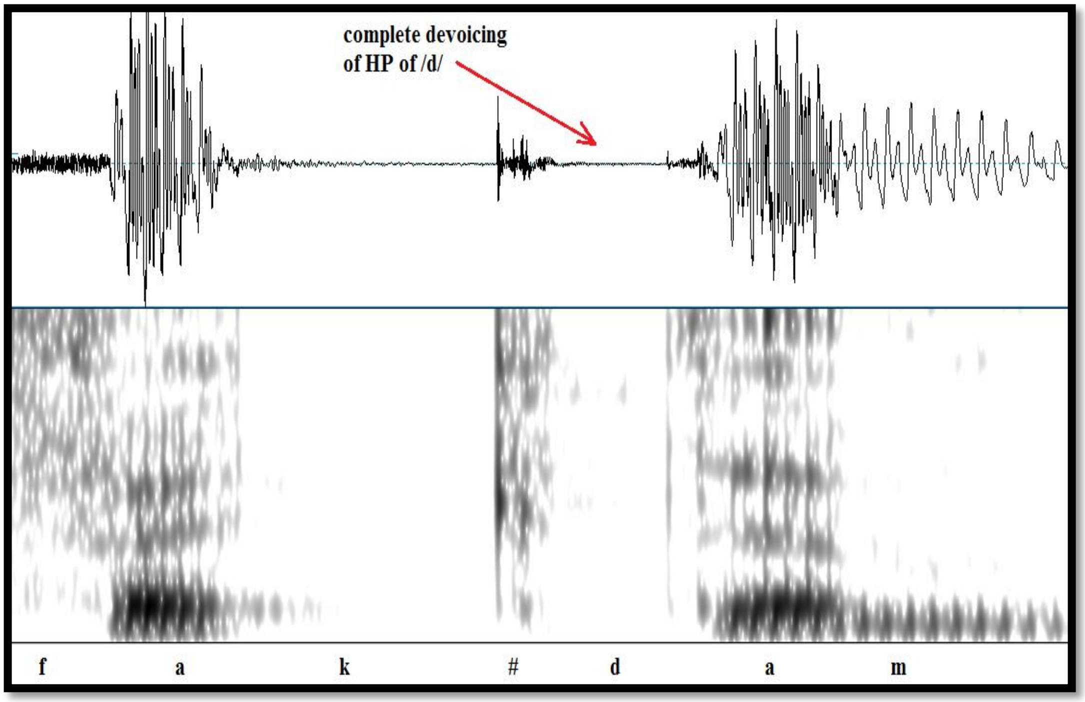


Figure 5.34 Progressive assimilation of voicelessness in -V+V voice context /fak#dam/. Complete devoicing of HP of /d/. Excrescent vowel is also voiceless

Regressive assimilation of voice occurred in 28 tokens averaging 31% of the total tokens exhibiting voice assimilation. In this voice context, 27 tokens did not exhibit any type of voice assimilation. For /fak#dam/, 10 tokens exhibited progressive assimilation of voicelessness in which the TT /d/ gesture was devoiced and zero tokens exhibited regressive assimilation of voice. Both /ʒit#giʃ/ and /fak#giʃ/ also exhibited the highest number of instances of progressive assimilation of voicelessness with the TB /g/ gesture being devoiced in 27 tokens and 20 tokens respectively. As for the /ʒit#dis/ phrase, as opposed to the other three examples, 18 instances of regressive assimilation of voice occurred compared to only 8 instances of progressive assimilation of voicelessness.

The increase in speech rate in the -V+V voice context resulted in an increase in the number of instances of regressive assimilation of voice occurring across the word boundary averaging 59% of voice assimilation instances. The number of tokens exhibiting progressive assimilation of voicelessness decreased to 42 tokens. The number of tokens not exhibiting voice assimilation also decreased to 19 tokens in fast speech rate compared to 27 tokens in normal speech rate.

5.5.1.1 Ratio of voice assimilation spread into HP in +V-V voice context

The spread of voicing and voicelessness into the HP of C1 and C2 as a result of voice assimilation was measured in both regressive and progressive voice assimilation. Results of the previous section show that in all the tokens of the +V-V voice context, only regressive assimilation of voicelessness occurred. As a result, in anticipation of the voicing of C2, the voiced TB /g/ gesture and voiced TT /d/ gesture are affected by voicelessness as illustrated in table 5.40.

Token	CI HP	Devoicing of C1 HP	% devoicing	C2 HP	Voicing of C2 HP	% voicing
/ʃid#tal/	102ms	64ms	62%	105ms	0ms	0%
/ʃid#kif/	125ms	52ms	41%	67ms	0ms	0%
/dag#tal/	119ms	56ms	47%	87ms	0ms	0%
/dag#kif/	105ms	56ms	53%	104ms	0ms	0%

Table 5.40 Regressive assimilation of voicelessness in +V-V voice context at normal speech rate. Mean C1 and C2 HP, mean duration of devoicing in HP of C1, and mean % of HP devoicing of C1

As a result of the spread of regressive assimilation of voicelessness, the TT /d/ gesture in /ʃid#tal/ is affected most by devoicing with the mean devoiced duration averaging 64ms, which is 62% of the mean HP. In /ʃid#kif/, the average devoiced duration of the mean HP of TT /d/ gesture was shorter averaging 52ms or 41% of the mean HP. The average devoiced duration of the mean HP of the TB /g/ gesture in /dag#tal/ was 56ms, or 47% of the mean HP. Finally, in /dag#kif/, the devoiced duration averaged 56ms or 53% of the mean HP of the TB /g/ gesture.

It is also worth noting that regressive assimilation of voicelessness spreads more in sequences where stops across the word boundary were homorganic as highlighted in figure 5.35. In both /ʃid#tal/ and /dag#kif/, the percentage of devoicing into the mean HP of voiced C1 averaged 62% and 53% respectively which was higher than in the heterorganic sequences /ʃid#kif/ and /dag#tal/ where it averaged 41% and 47% respectively.

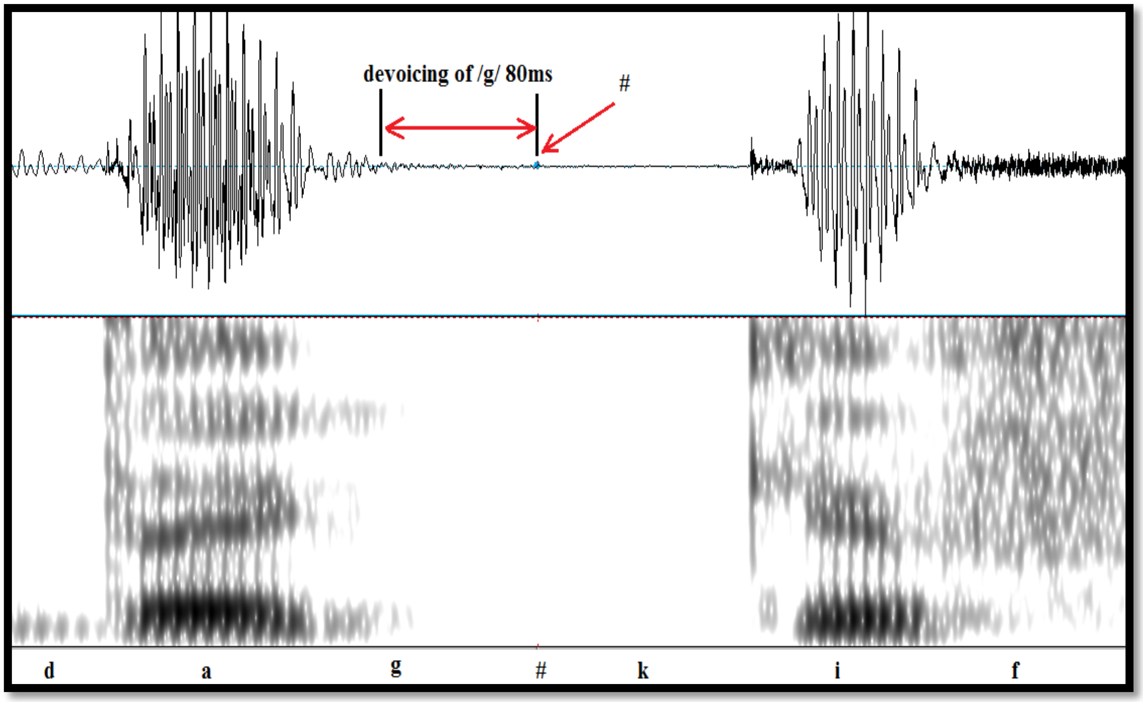


Figure 5.35 Regressive assimilation of voicelessness in homorganic sequence +V#-V /dag#kif/. HP of /g/=107ms, duration of devoicing =80ms. Absence of C1 release results in increase in % spread of voice assimilation into HP of C1

The increase in speech rate resulted in a decrease in the duration of devoicing spread into the HP of C1 as highlighted by the results in table 5.41. However, it is also worth noting that the HP of C1 and C2 also decreased as a result of the increase in speech rate as noted previously when investigating timing relations (sections 4.2 and 5.2). As a result of this, the ratio of devoicing spread into the HP of C1 did not considerably differ as a result of the increase in speech rate. For example in /ʃid#kif/, the mean devoicing duration into the HP of the TT /d/ gesture in normal speech rate averaged 52ms which was 41% of the mean HP. On the other hand, at the fast speech rate, although this duration averaged 39ms the devoicing duration averaged 38% of the HP. Therefore there was a decrease of only 3% in the percentage of devoicing spread into the mean HP of C1.

Furthermore, similar to what occurred at normal speech rate, the duration of devoicing into the HP of voiced C1 increased in both homorganic sequences /ʃid#tal/ and /dag#kif/ in comparison with the other heterorganic sequences /ʃid#kif/ and /dag#tal/.

Token	CI HP	Devoicing of C1 HP	% devoicing	C2 HP	Voicing of C2 HP	% voicing
/ʃid#tal/	81ms	46ms	56%	81ms	0ms	0%
/ʃid#kif/	101ms	39ms	38%	57ms	0ms	0%
/dag#tal/	87ms	36ms	41%	76ms	0ms	0%
/dag#kif/	81ms	48ms	59%	81ms	0ms	0%

Table 5.41 Regressive assimilation of voicelessness in +V-V voice context at fast speech rate. Mean C1 and C2 HP, duration of devoicing in HP of C1, and % of devoicing in HP of C1

5.5.1.2 Ratio of voice assimilation spread into HP in –V+V voice context

Previous results (section 5.5.1) reveal that in the –V+V voice context, both regressive assimilation of voice and progressive assimilation of voicelessness is found across the word boundary. In order to investigate the ratio of voice assimilation spread into the HP of the target segment as carried out on the +V-V voice context, the results are divided according to the direction of voice assimilation for each token.

At normal speech rate, there were 29 instances of regressive assimilation of voice from a total of 90 voice assimilation instances (table 5.42). Vocal fold vibration spread throughout the mean HP of C1 in all the tokens resulting in C1 becoming 100% voiced in both homorganic and heterorganic sequences as highlighted in figure 5.36. For example, in /ʒit#dis/, the mean HP of the TT /t/ gesture averaged 82ms with voicing spreading through 100% of the mean HP. The only exception was in /fak#dam/ where at normal speech rate regressive voice assimilation did not occur.

Token	CI HP	Voicing of C1 HP	% voicing	C2 HP	Devoicing of C2 HP	% devoicing
/ʒit#dis/	82ms	82ms	100%	82ms	0ms	0%
/ʒit#giʃ/	83ms	83ms	100%	61ms	0ms	0%
/fak#dam/	-	-	-	-	-	-
/fak#giʃ/	83ms	83ms	100%	83ms	0ms	0%

Table 5.42 Regressive assimilation of voice in -V+V voice context at normal speech rate. Mean C1 and C2 HP, duration of voicing in HP of C1, and mean % of voicing of HP of C1

The same ratio of voicing spreading into the mean HP of C1 was exhibited by at fast speech rate (table 5.43). As previously seen (table 5.39), the increase in speech rate resulted in an increase in the number of instances of regressive voice assimilation where 59 instances occurred as compared to 29 instances at normal speech rate in the –V+V voice context. Similar to normal speech rate, vocal fold vibration spread through 100% of the mean HP of voiceless C1 as a result of complete regressive voice assimilation.

Token	CI HP	Voicing of C1 HP	% voicing	C2 HP	Devoicing of C2 HP	% devoicing
/ʒit#dis/	70ms	70ms	100%	70ms	0ms	0%
/ʒit#giʃ/	79ms	79ms	100%	50ms	0ms	0%
/fak#dam/	70ms	70ms	100%	74ms	0ms	0%
/fak#giʃ/	68ms	68ms	100%	68ms	0ms	0%

Table 5.43 Regressive assimilation of voice in -V+V voice context at fast speech rate. Mean C1 and C2 HP, duration of voicing in HP of C1, and mean % of voicing of HP of C1

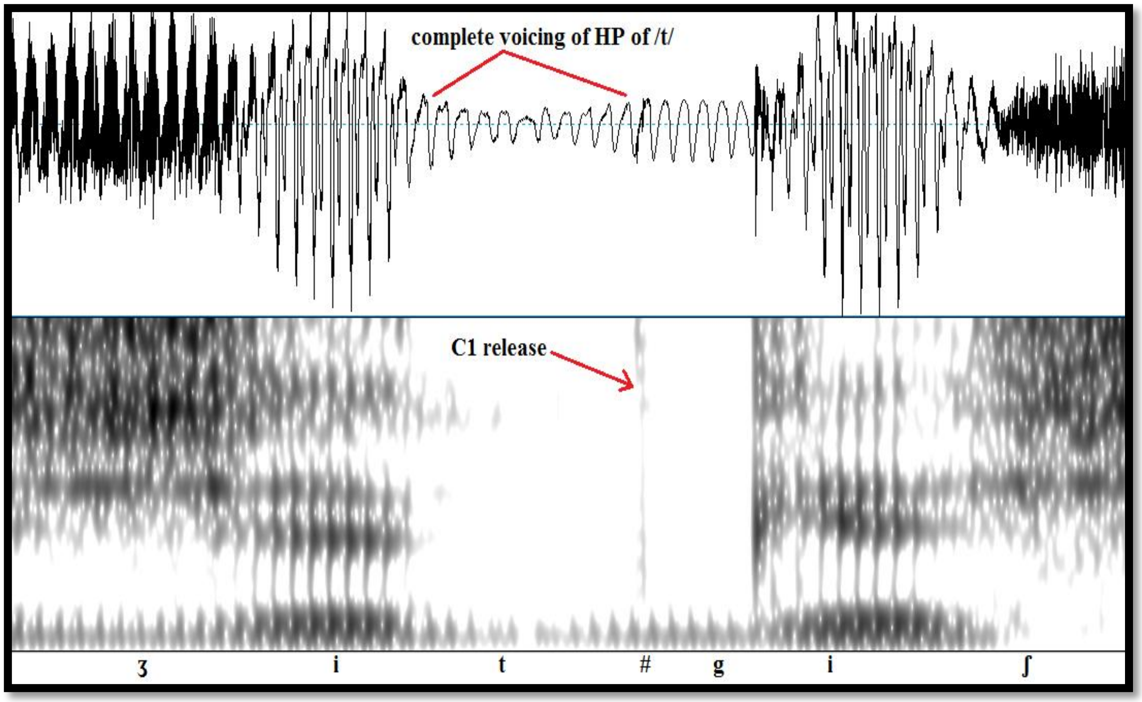


Figure 5.36 Complete regressive assimilation of voice of TT /t/ gesture in –V+V /ʒit#giʃ/. HP of /t/=89ms completely voiced

However, progressive assimilation of voicelessness occurring in the –V+V voice context exhibited a different pattern of voice assimilation spreading. Progressive assimilation of voicelessness occurred in 65 tokens out of a total of 93 tokens exhibiting voice assimilation. Similar to the spread of voicelessness into the HP of C1 as a result of regressive voice assimilation in the +V-V voice context, devoicing was partial and did not spread 100% into the HP of the voiced C2 in normal speech rate as shown in table 5.44. In /ʒit#dis/, the devoiced duration of voiced TT /d/ gesture averaged 60ms or 46% of the mean HP (figure 5.37). In /ʒit#giʃ/ this duration averaged 46ms or 67% of the mean HP of the TB /g/ gesture. In /fak#dam/, 32% of the mean HP of the TT /d/ gesture was devoiced. Finally, in the homorganic sequence /fak#giʃ/ the mean HP of the TB /g/ gesture was 80% devoiced which was higher than in the other homorganic sequence /ʒit#dis/.

Token	CI HP	Voicing of C1 HP	% voicing	C2 HP	Devoicing of C2 HP	% devoicing
/ʒit#dis/	106ms	0ms	0%	106ms	60ms	46%
/ʒit#giʃ/	119ms	0ms	0%	68ms	46ms	67%
/fak#dam/	118ms	0ms	0%	97ms	32ms	32%
/fak#giʃ/	112ms	0ms	0%	112ms	90ms	80%

Table 5.44 Progressive assimilation of voicelessness in -V+V voice context at normal speech rate. Mean C1 and C2 HP, devoicing of HP of C2, and mean % of HP devoicing of C2

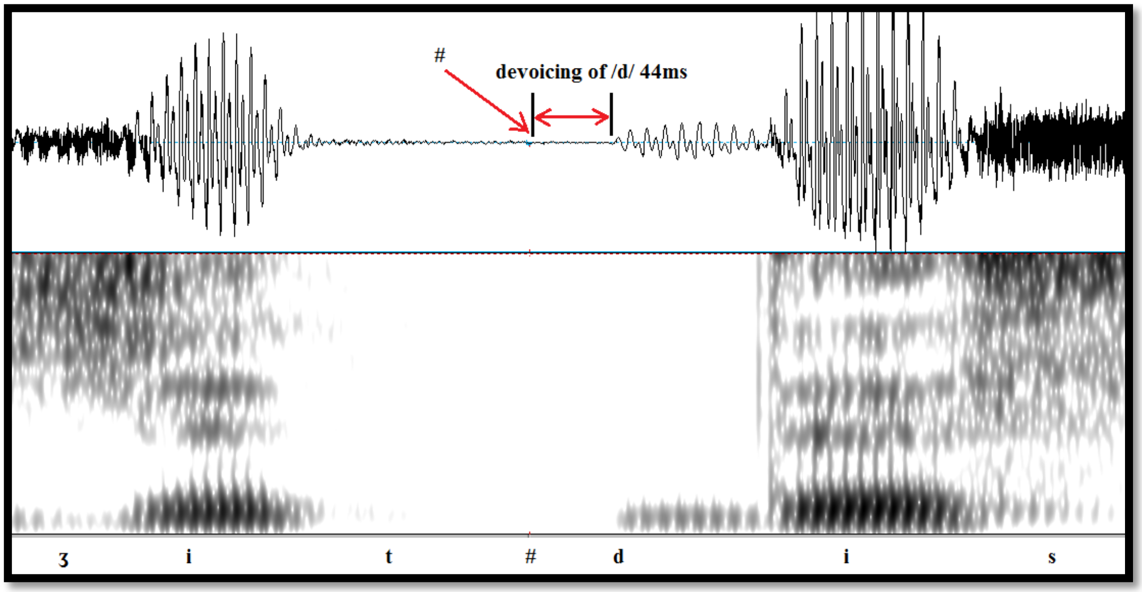


Figure 5.37 Progressive assimilation of voice in –V#+V context /ʒit#dis/. HP of /d/=118ms where 44ms was devoiced

The increase in speech rate resulted in a decrease in the number of instance of progressive assimilation of voicelessness in the –V+V voice context. Compared to normal speech rate where 65 instances occurred out of a total of 93, the number of tokens exhibiting progressive voice assimilation of voicelessness decreased to 42 from a total of 101 tokens where voice assimilation occurred as seen in table 5.45. In /zit#dis/, 67ms of the mean HP of the TT /d/ gesture was devoiced. In /ʒit#giʃ/, 42ms of the mean HP of the TB /g/ gesture was devoiced. As for /fak#dam/ and /fak#giʃ/, 34ms and 69ms respectively of the mean HP of C2 was devoiced. However, an increase in the ratio of devoicing spread into the HP of C2 in this voice context increased as the speech rate increased is observed (table 5.45). This is noticeable in /ʒit#dis/ and /ʒit#giʃ/ where devoicing spread into the HP of C2 was 100% and 90% respectively whereas at normal speech rate these figures for devoicing spread were 46% and 67% respectively.

Token	CI HP	Voicing of C1 HP	% voicing	C2 HP	Devoicing in C2 HP	% devoicing
/ʒit#dis/	67ms	0ms	0%	67ms	67ms	100%
/ʒit#giʃ/	90ms	0ms	0%	46ms	42ms	90%
/fak#dam/	83ms	0ms	0%	83ms	34ms	40%
/fak#giʃ/	81ms	0ms	0%	81ms	69ms	85%

Table 5.45 Progressive assimilation of voicelessness in –V+V voice context at fast speech rate. Mean C1 and C2 HP, devoicing of HP of C2, and mean % of HP devoicing of C2

5.5.2 The effect of excrescent and epenthetic vowels on voice assimilation across the word boundary

Previous results (section 5.3.3.3) indicate that excrescent and epenthetic vowels differ in how they are affected by the voicing context of adjacent segments. The voice values of excrescent vowels are more influenced by and therefore more dependent on the voicing context of the adjacent segments. At normal speech rate, results show that 99% of excrescent vowels in the –V-V voice context occurred voiceless whilst 96% occurred voiced in the +V+V context. On the other hand, the independence of the epenthetic vowels was particularly evident in the –V-V voice context. Although both adjacent segments occurred voiceless, in normal speech rate 77 % of the epenthetic vowels occurring in this voicing context were voiced suggesting that unlike excrescent vowels, epenthetic vowels are more independent in terms of voicing. In this section, the voicing of excrescent and epenthetic vowels occurring at the word boundary as a result of the unmasked release between two adjacent stops gesture is further investigated in instances of regressive and progressive voice assimilation in–V+V and +V-V voice contexts. The resulting voice values of excrescent and epenthetic vowels indicate whether these vowels block the voice assimilation process or not. For example, where regressive assimilation of voice in the –V+V voice context occurs, the resulting voiced excrescent or epenthetic vowel indicates that it was transparent to voice assimilation whereas a resulting voiceless excrescent or epenthetic vowels indicates the blocking of voice assimilation.

5.5.2.1 Effect of excrescent vowels on voice assimilation

The results reveal that voice assimilation directly affects the voice value of excrescent vowels occurring at the word boundary of the C#C sequence. The voice value of the excrescent vowel is always in agreement with the voicing of the trigger segment, never the target segment, regardless of the direction in which voice assimilation occurs. The results in table 5.46 reveal that as a result of regressive voice assimilation in the –V+V context, excrescent vowels were voiced at both speech rates as a result of the trigger being voiced as illustrated in figure 5.38. In this voice context, there were 2 instances of regressive assimilation of voice at normal speech rate and 15 instances at fast speech rate. These were found in the /ʒit#giʃ/ and /fak#dam/ phrases. All resulting 17 excrescent vowels at both speech rates were voiced.

In the other +V-V voice context, regressive assimilation of voicelessness resulted in excrescent vowels occurring as voiceless as a result of the trigger being voiceless. Occurring in /ʃid#kif/ and /dag#tal/ phrases, a total of 52 instances of regressive assimilation of voicelessness in normal speech rate and 43 instances in fast speech rate occurred in this voice context. All 95 excrescent vowels were voiceless as a result of the spread of voicelessness from the voiceless trigger.

Voice context	**Normal**			**Fast**		
	assimilation (N)	**excrescent vowel (N)**		**assimilation (N)**	**excrescent vowel (N)**	
-V+V	2	voiced	voiceless	15	voiced	voiceless
		2	0		15	0
+V-V	52	voiced	voiceless	43	voiced	voiceless
		0	52		0	43

Table 5.46 Regressive voice assimilation in both voice contexts tokens and the resulting voice value of excrescent vowel

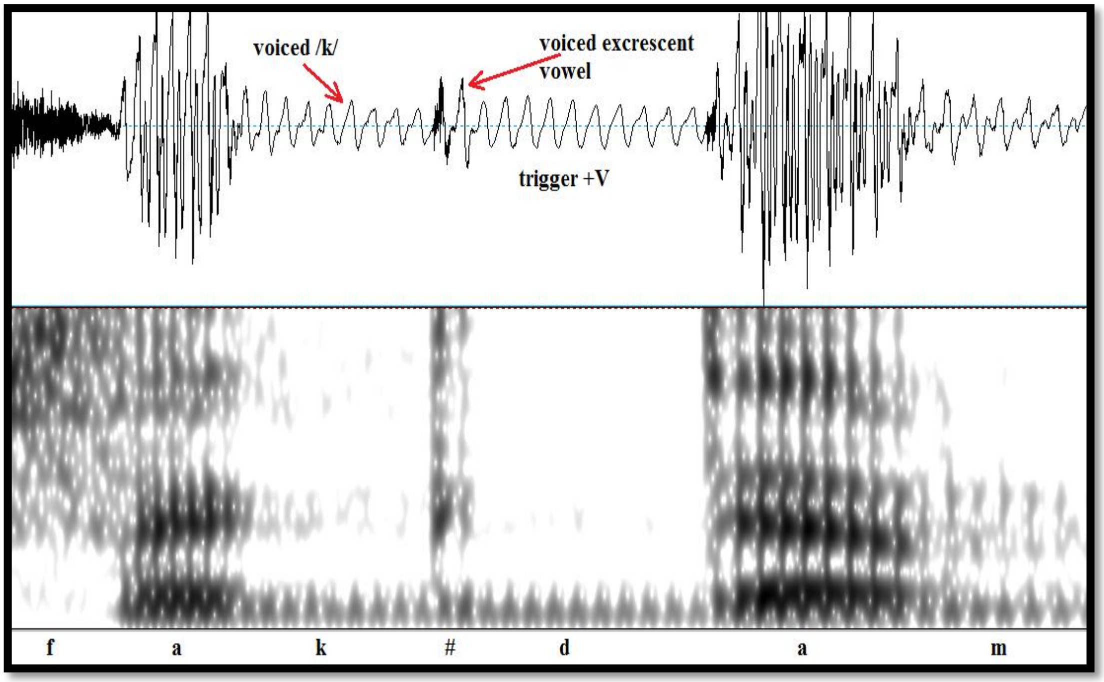


Figure 5.38 Regressive assimilation of voicing in –V+V context in /fak#dam/ at fast speech rate. Trigger TT /d/ gesture is voiced resulting in voiced excrescent vowel

The voicing of excrescent vowels in cases of progressive voice assimilation are presented in table 5.47. In the -V+V voice context, excrescent vowels were voiceless as a result of the voice value of the trigger being voiceless and voicelessness spreading throughout the vowel. This applies to both normal and fast speech rates. Excrescent vowels were found in the /ʒit#giʃ/ and /fak#dam/ phrases as highlighted in figure 5.39. As for the +V-V voice context, no instances of progressive voice assimilation occurred in either speech rate as previously noted (section 5.5.1).

Voice context	**Normal**			**Fast**		
	assimilation (N)	**excrescent vowel (N)**		**assimilation (N)**	**excrescent vowel (N)**	
-V+V	41	voiced	voiceless	29	voiced	voiceless
		0	41		0	29
+V-V	0	voiced	voiceless	0	voiced	voiceless
		-	-		-	-

Table 5.47 Progressive voice assimilation in both voice contexts and resulting voice value of word boundary excrescent vowel

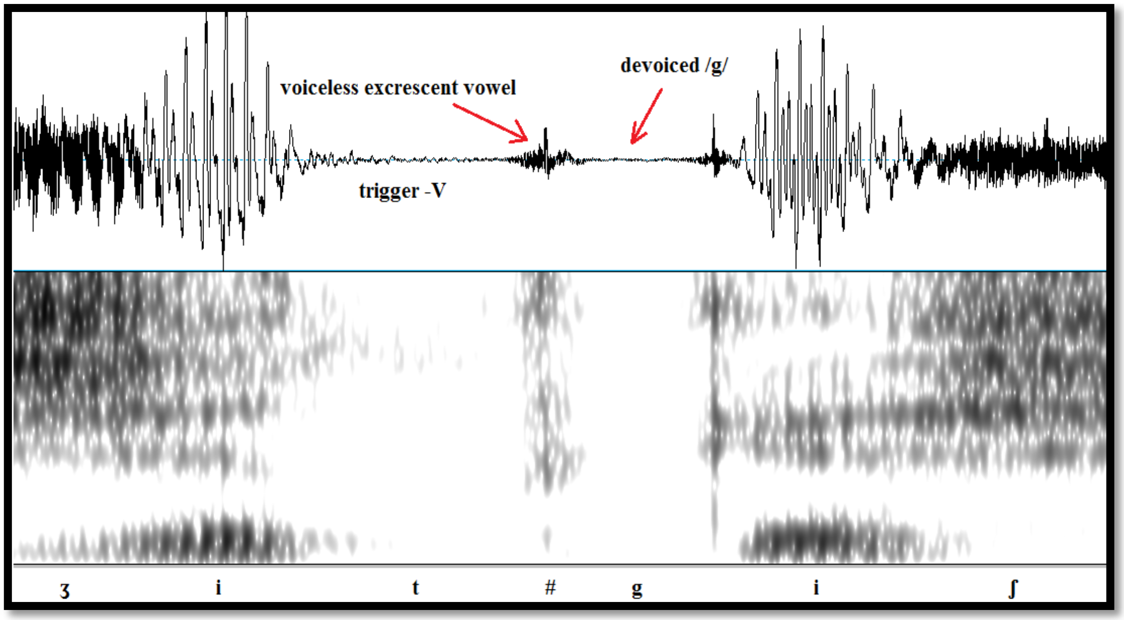


Figure 5.39 Progressive assimilation of voicelessness in –V+V context /ʒit#giʃ/. Trigger /t/ is voiceless resulting in voiceless excrescent vowel

These results indicate that excrescent vowels are transparent to and do not block the spread of voice assimilation across the word boundary.

5.5.2.2 Effect of epenthetic vowels on voice assimilation

Due to the complicated voice combinations within stops of SF and SI clusters of the CC#CC sequence, /hatk#gdi:m/ and /ʕagd#ktab/ phrases were selected for this investigation. The reason for this is that stops in both the SF and SI clusters of these phrases agree in voicing, resulting in a +V-V and a –V+V voice context occurring across the word boundary consistent with the excrescent vowels of the C#C sequence previously investigated.

The independent voice value of epenthetic vowels occurring at the word boundary of the CC#CC sequence was particularly evident in the –V-V voice context (section 5.3.3.3). Although both segments adjacent to the word boundary occurred voiceless, in normal speech rate 77.5% of the epenthetic vowels occurring in this voicing context were voiced in an indication that unlike excrescent vowels, epenthetic vowels are more independent in terms of voicing. In the +V+V voice context, epenthetic vowels were 100% voiced in both normal and fast speech rates. Further highlighting the independent voice value of epenthetic vowels, in the remaining -V+V and +V-V voice contexts, the percentage of epenthetic vowels occurring as voiced was 93% and 97% respectively in normal speech rate and 96% and 93% respectively in fast speech rate. For this reason, epenthetic vowels here are specified to be voiced.

Results show that the occurrence of epenthetic vowels at the word boundary of the CC#CC sequence blocks the spread of voice assimilation. In the /hatk#gdi:m/ phrase at normal speech rate, epenthetic vowels occurred at the word boundary in 27 tokens out of a total of 30 tokens due to the long lag duration between stops adjacent to the word boundary. The results indicate that the spread of voice assimilation across the word boundary is blocked as a result of the epenthetic vowel as illustrated in figure 5.40. In all 27 tokens, the TB voiced /g/ gesture of the SI cluster retained voicing and was therefore not affected by voice assimilation due to the presence of the epenthetic vowel.

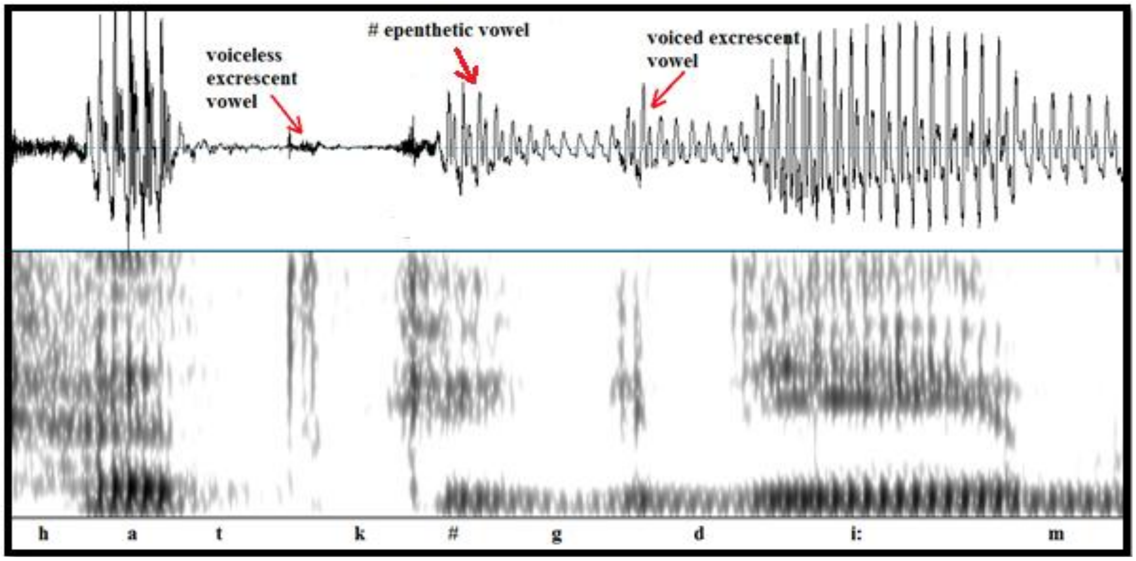


Figure 5.40 Voicing assimilation blocking by epenthetic vowel at word boundary in /hatk#gdi:m/.

Interestingly, in cases where epenthetic vowels did not occur at the word boundary, voice assimilation across the word boundary did occur. As mentioned earlier, in the /hatk#gdi:m/ phrase, three tokens were produced with stop closure overlap and no epenthetic vowels occurred. This was a result of closer gestural coordination due to the homorganic nature of both stops adjacent to the word boundary. In these tokens, progressive assimilation of voicelessness was not blocked from spreading across the word boundary. As a result, the TB /g/ gesture of the SI cluster /gd/ was totally devoiced. However, devoicing did not spread into the HP of C2 of the SI cluster as highlighted in figure 5.41.

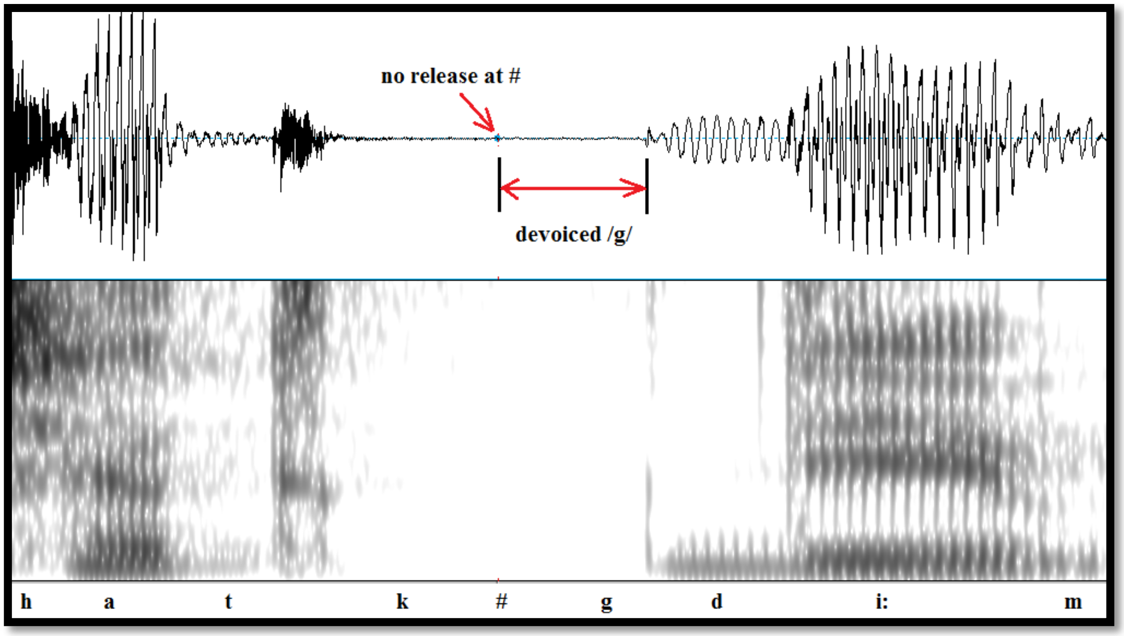


Figure 5.41 Absence of epenthetic vowel at word boundary of /hatk#gdi:m/ due to stop closure overlap permits the spread of progressive assimilation of voicelessness resulting in a devoiced /g/=85ms. Voicing is initiated at onset of closure of C2 of the SI cluster

In the CC#CC sequence in the /ʕagd#ktab/ phrase, epenthetic vowels occurred at the word boundary of all 30 tokens due to the lack of stop closure overlap in this position. In this case, all epenthetic vowels here were fully voiced. The results shows that the voiceless TB /k/ gesture of the SI /kt/ cluster was not affected by any progressive assimilation of voice in 27 out of a total of 30 tokens. In these tokens, vocal fold vibration terminates at the offset of the epenthetic vowel and does not spread into the HP of SI C1. Similarly, the voiced TT /d/ gesture of the /SF /gd/ cluster was not affected by any regressive assimilation of voicelessness. This is further evidence that the epenthetic vowel blocks the spread of voice assimilation spreading across the word boundary.

Despite this, the voiceless TB /k/ gesture of the SI cluster /kt/ was fully voiced in the remaining three repetitions. But whether this is a result of progressive assimilation of voice from the preceding voiced stop /d/ or a voicing tail from the epenthetic vowel is debatable. Nevertheless, 90% of the tokens investigated clearly reveal that voicing does not spread into the HP of the following voiceless SI cluster.

This further supports the assumption that epenthetic vowels are not transparent and block the spread of voice assimilation.

5.5.3 Summary

The general pattern of voice assimilation spread across the word boundary of the C#C sequence in TLA also reveals that regressive right-to-left voice assimilation is more frequent occurring in 68% of all the instances of voice assimilation in normal speech rate and 78% of all instances in fast speech rate. However, progressive voice assimilation was also exhibited in a number of tokens.

The voice context of the stops involved plays a major role in determining the direction of voice assimilation spreading. Progressive voice assimilation did not occur in the +V-V voice context where in all instances of voice assimilation only regressive assimilation of voicelessness was exhibited. The devoicing of the target stop was not completely devoiced. In the –V+V context, both regressive and progressive voice assimilation was found. In terms of the ratio of voice assimilation spread into the HP of target segments, regressive assimilation of voice was total with voicing spreading throughout 100% HP of the target segment in the –V+V voice contexts. On the other hand, progressive assimilation of voicelessness did not spread throughout the whole HP of the target segment, with the exception of the –V+V voice context /ʒit#dis/ phrase in fast speech rate where 100% of the mean HP of C2 /d/ was devoiced. In the +V-V voice context, despite the mean duration of voicelessness spread into the target segment being higher at normal speech rate compared to fast speech rate, the percentage of voicelessness spreading into the HP did not differ considerably since the mean HP of the target segment was also longer in the normal speech rate. As a result, speech rate does not directly affect the spread of voice assimilation in this voice context However, the spread of voicelessness into the HP of the target segment in the –V+V voice context did increase as a result of the increase in speech rate.

Previous results (section 5.3.3) have shown that the excrescent/epenthetic vowel distinction is valid in TLA. The results in section 5.5.2 provide further support of this distinction. The voice value of the excrescent vowel is dependent on the voice context of the adjacent segments and the direction in which voice assimilation occurs. In all instances of voice assimilation where excrescent vowels occurred at the word boundary, the voice value of the excrescent vowel is always in agreement with the voice value of the trigger segment in both regressive and progressive voice assimilation. In other words, excrescent vowels are transparent to and do not block the spread of voice assimilation across the word boundary.

On the other hand, being more independent in their voice value, epenthetic vowels appear to block the process of voice assimilation. In the /hatk#gdi:m/ phrase, the word boundary epenthetic vowel clearly blocks the spread of progressive assimilation of voicelessness. As for the /ʕagd#ktab/ phrase, the general pattern reveals that progressive assimilation of voice did not spread into the following SI cluster in 90% of the tokens. Similarly, C2 of the voiced SF cluster /gd/ was not affected by any regressive assimilation of voicelessness. The results highlighted in both these phrases are sufficient to claim that epenthetic vowels are not transparent and block the spread of voice assimilation from spreading across the word boundary. The results provide further evidence that epenthetic and excrescent vowels belong to two distinct categories as previously suggested (section 5.3.3).

Chapter 6 Discussion and conclusion

This final chapter discusses the findings and results of both the EPG in chapter 4 and acoustics in chapter 5. The chapter also serves as a conclusion to this study and reflects on its findings.

6.1 Discussion

This section addresses the theoretical implications and interpretations of the data where the main findings of the study are linked to theoretical assumptions. The discussion is divided into four sections. The first section discusses the results of the intergestural timing of stops in the four sequence types. The second section focuses on the results of the patterns of gestural coordination in the C#C, C#CC, CC#C, and CC#CC sequences and the implications that these results have on phonology. The third section reviews the results of the influence the order of place of articulation has on gestural coordination. The final section in the discussion focuses on the results of the voice assimilation.

6.1.1 Gestural timing

This section discusses the results of section 4.2 of the EPG data and section 5.2 of the acoustics data, focusing on the timing of SF and SI stops and clusters occurring in different sequence types. The results indicate that the increase in the number of stops in a sequence has an effect on the duration of stops adjacent to the word boundary. To the best of my knowledge, to date no study has investigated the effect of an increase in the number of stops in a heterosyllabic sequence spanning the word boundary on the timing of segments. Literature examining the timing pattern for stops in C#CC, CC#C and CC#CC sequences is limited. Studies concerning the timing of stops across the word boundary have only focused on comparing the timing of stops in a C#C sequence with VCC#, and #CCV sequences (Byrd 1996; Cho 2001; Davidson & Roon 2008). The maximum number of stops in the sequences previously investigated was two. The results of these previous studies reveal that the total duration of the sequence was longer when occurring across the word boundary and as a SF cluster than when occurring as a SI cluster. Other studies examined gestural timing for SF and SI clusters within syllable boundaries (Browman & Goldstein 1988; Byrd 1994) and concluded that gestural timing for SI clusters is shorter and more stable than for SF clusters as mentioned in section 5.2.2.5. However, the fact that speech gestures can affect each other is not confined to SF and SI stops within syllable and word boundaries but also spreads across word boundaries and is also affected by the number of stops as the results suggest.

The results in sections 4.2.1 and 5.2.1 show that the singleton stop in tokens of the **C**#C exhibits a decrease in duration when followed by a SI cluster in tokens of the **C**#CC sequence. In section 4.2.1 of the EPG data, this decrease ranged from 11ms-29ms. In section 5.2.1 of the acoustics data, the decrease ranged from 11ms-15ms. Similarly, the results indicate that the SI singleton stop in tokens of the C#**C** sequence also exhibits a decrease in the duration when preceded by a SF cluster in tokens of the CC#**C** sequence. This decrease ranged from 18ms to 34ms in the EPG data (section 4.2.2) as opposed to a range of 14ms to 17ms in the acoustics data (section 5.2.2).

This decrease in duration could be caused by the speaker's need to accommodate the time necessary for articulating the additional gesture in the sequence in the process of coarticulation. In case of the decrease in the duration of the SF stop, this may be caused by anticipatory coarticulation. The duration of the SF stop gesture in tokens of the **C**#CC sequence decreases in anticipation of the timing of the following SI cluster. However, the decrease in the duration exhibited by the SI stop gesture as a result of the increase in the number of stops in the preceding SF position seems be motivated by carryover coarticulation. Due to the length of the duration of the SF cluster in tokens of the **CC**#C sequence, the duration of the SI stop gesture decreases in comparison to that occurring in the C#**C** sequence. In this sense, there seems to be a trading relation between the timing of gestures spanning the word boundary. When followed or preceded by a cluster, SF and SI stop gestures respectively exhibit a decrease in their duration.

However, the results reveal that when occurring as part of a cluster, the effect of the increase in the number of stops in a sequence on the duration of the SF C2 in C**C**#C and SI C1 in C#**C**C sequences differ as a result of the increase in the number of stops when both these stops occur in the CC#CC sequence. The results show that SF C2 in tokens of the C**C**#C sequence exhibits a decrease in duration as a result of the increase in the number of stops in SI position in tokens of the C**C**#CC sequence. In normal speech rate, this decrease ranged from 5ms-22ms in the EPG data (section 4.2.1) and from 10ms-17ms in the acoustics data (section 5.2.1). On the other hand, the EPG data (section 4.2.2) and the acoustics data (section 5.2.2) show that SI C1 stop gestures in tokens of the C#**C**C sequence do not exhibit this decrease as a result of the increase in the number of stops in SF position in tokens of the CC#**C**C sequence. The only exceptions were to be found in tokens of the TB stop gestures /k/ and /g/. The duration of these SI C1 stops in tokens of the C#**C**C sequence was longer than when they occurred in tokens of the CC#**C**C sequence.

Similarly, the results of the timing of SF and SI clusters in sections 4.2.3 and 4.2.4 of the EPG data and 5.2.3 and 5.2.4 of the acoustics data reveal that they exhibit different timing patterns when the number of stop gestures increases on the adjacent side of the word boundary. The duration of the SF cluster when followed by a SI singleton stop gesture in tokens of the **CC**#C sequence decreases as the number of stops in SI position increases as in tokens of the **CC**#CC sequence. However, SI clusters in tokens of the C#**CC** sequence are not greatly affected by the number of stops in SF position in tokens of the CC#**CC** sequence. With the exception of the /tk/ SI cluster, the timing of the other SI clusters did not vary.

Several studies have documented differences in the timing of SF and SI stops (Byrd 2003; Gafos 2002; Marin & Pouplier 2002), and in the C-centre hypothesis (Browman & Goldstein 1988, 2000). The results here are in line with the results of these studies, namely, that SF clusters exhibit less gestural coordination and are more variable in timing than SI clusters. The variability in the timing of SF clusters in tokens of the **CC**#C and **CC**#CC sequences is a result of the different coordination patterns exhibited between stops in these clusters. In section 4.3.2.3 of the EPG data and 5.3.2.3 of the acoustics data, a relatively long epenthetic vowel is found between stops of the SF cluster in tokens of the **CC**#C sequence therefore increasing the duration of the whole cluster. However, when occurring in tokens of the **CC**#CC sequence, the SF cluster exhibited tighter gestural coordination resulting in a short excrescent vowel between the stops and therefore the duration is shorter. For this reason, SF clusters exhibit a decrease in their duration when occurring in tokens of the **CC**#CC sequence as the results reveal.

The results indicate that SI clusters exhibited more stability even when there is an increase in the number of stops on the adjacent side of the word boundary. Results of sections 4.2.4 of the EPG data and 5.2.4 of the acoustics data indicate that the SI cluster in tokens of both the C#**CC** and CC#**CC** sequences are more stable in their timing and were less variable than the SF clusters.

The gestural coordination pattern found between stops of the SI clusters in tokens of both sequences is similar as the results in section 4.3.2.2 suggest. An identical tight gestural coordination is exhibited by the SI cluster in tokens of both the C#**CC** and CC#**CC** sequences resulting in a short excrescent vowel occurring between the stops. In line with other studies (Byrd 2003; Gafos 2002; Browman & Goldstein 1988, 2000), the temporal organization of SI cluster in tokens of the C#**CC** sequence and the CC#**CC** sequence was very close.

Another interesting result is that the timing of the SF stop gesture in tokens of the **C**#C and **C**#CC sequences are longer when followed by a heterorganic stop in SI position. In other words, when followed by a conflicting tongue gesture, the duration of the SF stop is longer than when followed by a homorganic stop. One reason for this increase in duration is that the following conflicting gesture stop requires more time and effort and in anticipation for this the HP of the stop gesture can be kept in place for a longer period since it is not involved in the production of the following gesture (Umeda 1977). Thus for example, the mean HP duration of the SF stop /k/ in /fak#kif/ and /fak#giʃ/ averaged 102ms and 104ms respectively when followed by a non-conflicting gesture in both examples (section 5.2.1.2). When followed by a conflicting gesture as in /fak#tal/ and /fak#dam/ where the TB gesture is followed by a TT /t/ and /d/ gesture, the mean HP of SF /k/ was longer averaging 119ms and 115ms respectively.

Finally, results revealed that across all stops and clusters investigated, the timing of gestures appears to decrease at fast speech rate. As a result of the increase in speech rate and the increase in the velocity of the articulators; in this study being the tongue, the duration of segments decreases (Gay 1981). This is evident in the timing of all stops and clusters investigated. Despite this, the timing pattern is not consistent in fast speech rate in comparison with the normal speech rate. It seems that the decrease in the duration of stops resulting from the increase in the number of stop gestures in sequences exhibited in normal speech rate is not consistent in fast speech rate. This may be due to the fact that the HP's of these stops have already decreased in their duration as a result of the increase in articulator velocity (Byrd & Tan 1996).

6.1.2 Gestural ccordination and epenthesis patterns

This section discusses the results of sections 4.3 of the EPG data and section 5.3 of the acoustics data. Intergestural timing and patterns of gestural coordination in tokens of the C#C, C#CC, CC#C, and CC#CC sequence types have been investigated. For the most part, the results of both the EPG and acoustics investigations are consistent, the only difference is that the percentage of unmasked releases between adjacent stops was smaller in the EPG data. This can be explained in terms of the intervals at which the EPG records tongue palate contact. EPG allows the monitoring of changes in tongue-palate contact patterns of a speech segment over time at intervals of ten milliseconds. Therefore, any ICI duration under 10ms was not recorded by the EPG frames. For this reason, the percentage of unmasked stops releases in the EPG data (section 4.3.1) was smaller than those found in the acoustic data (section 5.3.1) in positions where excrescent vowels occurred. Other than this slight variation, the results of both investigations are consistent.

The results indicate that there are two types of gestural coordination patterns between adjacent stops in TLA. This is evident in the lag and resulting ICI durations occurring between stop gestures in tokens of the four sequence types investigated. Results suggest that ICIs belong to distinct categories (section 5.3.3). The first type which occur at the word boundary in tokens of the C#C and CC#C sequences, in the SI cluster in tokens of the C#CC sequence, and between stops of the SF and SI clusters in tokens of the CC#CC sequence are excrescent vowels ranging from 14ms-20ms in normal speech rate. These are short in duration indicating a more cohesive gestural coordination pattern between stops. The second type is found between stops of the SF cluster in tokens of the CC#C sequence and at the word boundary in tokens of the C#CC and CC#CC sequences. These are longer in duration ranging from 43ms-51ms in normal speech rate indicating that gestural coordination between the stops is weak where gestures are further pulled apart. These differences between the two types of ICIs are observed in several studies (Browman & Goldstein, 1992, 1995; Gafos 2002; Gick & Wilson 2006; Haddad 1984; Davidson & Stone 2004).

Another interesting observation that further distinguishes the two types is the voice value of these vowels. Excrescent vowels seem to be more dependent in terms of voicing on the voice value of neighbouring segments whilst epenthetic vowels seem to be more independent and are usually specified as voiced. This seems to be caused by the the fact that the relatively longer duration of epenthetic vowels allows the initiation of vocal fold vibration during their production.

However, the results of these investigations are not in agreement with the literature with regards to the effect of speech rate on excrescent vowels since previous studies have claimed that they disappear in fast speech rate (Gafos 2002; Hall 2006). The increase in speech rate did not have an effect on excrescent vowels. The percentage of unmasked stop releases resulting in excrescent vowels and their duration are not affected by the increase in speech rate in either the EPG or the acoustic results. Epenthetic vowels, however, exhibited a decrease in duration when speech rate increased (Hall 2006). As a result, gestural coordination was tighter between stops where epenthetic vowels occurred in fast speech rates. This is well documented in the literature which notes that faster speaking rates cause gestures to slide together and as a result greater gestural overlap occurs (Huinck et. al 2004; Byrd & Tan 1996; Hall 2006).

In general, excrescent vowels result from a lack of stop closure overlap whereas epenthetic vowels are inserted by speakers to avoid stop sequences violating the syllabic template of TLA which allows a maximum of two stops to occur in a sequence. With regards to the epenthesis distribution pattern, the results indicate that it is controlled by the phonotactics which are governed by the syllabic template of TLA. In tokens of the C#C sequence, consisting of only two stops and therefore not violating the syllabic template of TLA, gestural coordination between these stops was very close resulting in transitional excrescent vowels where stop closure overlap was not observed. However, in tokens of both the C#CC and CC#C sequence, epenthesis was triggered due to the fact that the number of stops in the tokens of both sequences violates the syllabic template of TLA. This is in agreement with claims that epenthesis is applied in repairing illegal sequences (Zsiga 2003; Hall 2011). However, the pattern of epenthesis is similar in both sequence types. Epenthesis is found to occur between C1 and C2 in tokens of both sequence types suggesting weak gestural coordination in these positions. Closer gestural coordination is found between C2 and C3 stops in tokens of both sequences resulting in short excrescent vowels.

An interesting result is found in section 5.3.2.3.1 where a resyllabification process is found to occur in tokens of the CC#C sequence. Tokens of the CC#C sequence undergo a resyllabification or process where SF C2 of the C**C**#C sequence delinks and bonds with the SI singleton adjacent to the word boundary resulting in a SI cluster. The phonological boundary and syntactic boundary are not aligned in the CC#C sequence. The phonological boundary is actually within the SF cluster whereas the syntactic boundary is at the word boundary. Therefore, the syllabic configuration in tokens of the CC#C sequence undergoes an alternation process resulting in a syllabic configuration identical to that in tokens of the C#CC sequence due to the migration of the SF C2 coda in tokens of the C**C**#C sequence. Although being grammatically/lexically different, both the C#CC and CC#C sequences are phonologically the same.

Due to this resyllabification process, the gestural coordination pattern exhibited by CC#C was identical to that exhibited by the C#CC sequence the only difference is being the syntactic word boundary location. An identical epenthesis pattern is observed in both sequences. In anticipation of the three stop sequence, the epenthetic vowel is inserted between C1 and C2 stops in both sequences resulting in weak gestural coordination in these positions in order to fulfill the syllabic template of TLA. These epenthesis patterns in tokens of the C#CC and CC#C sequences are in line with the classification of Libyan Arabic as a VC dialect (Kiparsky 2003; Watson 2007), and are also similar to the epenthesis patterns found in Iraqi Arabic (Ito 1989).

Despite this, the results indicate that the pattern of epenthesis in homorganic sequences does not conform to the VC distinction. According to the VC and CV language distinction, consonants in a CCC sequence are viewed as phonological segments. As evidenced by the epenthesis pattern in tokens of the C#CC sequence, epenthetic vowels are usually inserted at the word boundary in accordance with the VC classification. However, the results indicate that where C1 and C2 of the sequence are homorganic, epenthesis does not occur categorically. Results of section 5.3.1.2 indicate that in /bat#tkasir/, 50% of the repetitions exhibited stop closure overlap across the word boundary and no epenthetic vowel was inserted between C1 and C2. This is also found in /nat#dkar/ and /ʃad#tkasir/ where 30% of the repetitions in each phrase exhibited stop closure overlap across the word boundary and epenthesis did not occur (please refer to table 5.20). This is due to the fact that in these examples a homorganic sequence of stops spans the word boundary. C1 and C2 stops share the same place of articulation and consist of only one articulatory gesture. As a result, in such cases, despite consisting of three segments phonologically, in articulatory terms these sequences consist of two gestures and therefore epenthesis is not triggered in some of these homorganic sequences. It can be justified that the constraint in the VC and CV language distinction is therefore based on gestures and not phonological segments in this context.

The pattern of epenthesis is different in tokens of the CC#CC sequence. Applying the same epenthesis pattern between C1 and C2 of the sequence as occurs in tokens of the C#CC and CC#C sequences, fails to conform to the syllabic template of TLA. The result of such a pattern in this four stop sequence is another three stop sequence C2C3C4. Therefore, in tokens of the CC#CC sequence, the epenthetic vowel is inserted at the word boundary between C2 and C3 of the sequence instead. As a result, closer gestural coordination is found between stops in both the SF and SI cluster where excrescent vowels are found to occur. Breaking up the sequence in this manner follows the syllabic template of TLA.

It can be argued that in cases where the phonotactics of TLA is violated, epenthesis is triggered. The results indicate that gestural coordination is weaker between gestures across word boundaries in stop sequences that exceed three stops. This seems to be caused by the fact that stops adjacent to the word boundary are not associated with a single lexical entry and belong to two separate words and therefore exhibit weak gestural bonding (Hardcastle 1985; Cho 1998, 2001).

The purpose of epenthesis is to prevent the occurrence of more than two stops in a sequence and therefore fulfill the syllabic template of TLA. Excrescent vowels, howver, occur even when template satisfaction is achieved. Therefore, it can be argued that speakers do not intentionally produce excrescent vowels but these are simply a phonetic by-product of two conflicting articulatory goals a result of gestural mistiming (Gick & Wilson 2006) where one gesture is not synchronized with the following gesture. Further evidence to support this argument can be found in the effect of speech rate on excrescent vowels since, as previously discussed, the increase in speech rate did not result in a decrease in or the disappearing of excrescent vowels. The lack of stop closure overlap results in a transitional excrescent vowel occurring between stops in the sequence (Browman & Goldstein 1990; Davidson & Stone 2004), where speakers do not intentionally insert the excrescent vowel.

Finally, longer lag durations found between homorganic stops spanning the word boundary have been observed. This can be analyzed by the time needed for an articulator responsible for a closure to be released and return to the same closure position than if it is followed by another separate articulator. Considering the tongue as being pluridimensional, i.e. the tip and body of the tongue can function as two separate articulators (Gibbon et al. 1993), the results show that when a TT gesture is followed by another TT gesture in a position where epenthesis is triggered, more time is needed for the same closure to be reinstated than if it was followed by a TB gesture.

6.1.3 CD vs DC order of place of articulation

This section discusses the results of the effect of the order of place of articulation on gestural coordination in the EPG data (section 4.4) and acoustics data (section 5.4). The results of both investigations are consistent, the only difference being the percentage of unmasked stop releases in both investigations. As previously explained (section 6.1.2) this was the result of the EPG not accounting for excrescent vowel with durations below 10ms. In general, a significant difference in gestural coordination between stops in the CD and DC order of place of articulation was found.

Closer gestural coordination is exhibited in tokens of the CD order of place of articulation where a TT gesture is followed by a TB gesture. The EPG and acoustics data reveal shorter lag durations between stop gestures in this order. Furthermore, longer stop closure overlap durations are exhibited in the CD order of place of articulation as indicated by the results of the EPG data (section 4.4.2). On the other hand, tokens of the DC order of place of articulation exhibited longer lag durations and shorter stop closure overlap durations as indicated by the EPG results. These tokens in which a TB gesture is followed by a TT gesture reveal that the gestures are not closely synchronised resulting in a decrease in gestural coordination. These results have been well documented in the literature (Hardcastle & Roach 1979; Byrd & Tan 1996; Zsiga 2000, 2003; Chitoran et al 2002; Kochetov 2007).

However, if the differences in gestural coordination between stop gestures in both orders of articulation are to be explained in terms of perceptual recoverability where stop closures of dorsal TB /k/ and /g/ would threaten their perception if the release is masked by the closure of the following coronal TT /t/ and /d/ stops (Chitoran et al 2002; Kochetov 2007), then it can be anticipated that more unmasked stop releases to be found in the DC order of place of articulation. The EPG data (section 4.4.1) indicates that more unmasked releases are found in the DC order of articulation. This is due to the fact that shorter lag durations, most likely below 10ms, are found in the CD order of place of articulation as a result of closer gestural coordination. For this reason the EPG results indicate more unmasked stop releases in the DC order of place of articulation. However, the acoustics data results (section 5.4.1) indicate that the percentage of unmasked stop releases are similar in both orders of place of articulation. Therefore, the results indicate that perceptual recoverability does not account for the systematic effect of the order of place of articulation on gestural coordination.

It seems more likely that longer lag durations are found in the DC order of place of articulation of stops due to limitations in the articulatory movement of the tongue. If the tongue is thought of as pluridimensional, the back of the tongue is closer to the palate and closer to the jaw pivot therefore requiring less time and muscle activity to form a TB gesture. On the other hand, the tongue tip is farther away from the palate and requires the movement of two muscles to form an alveolar closure (Hardcastle 1979). As a result, more time is needed to for the formation of a TT stop gesture in comparison with the time needed for the formation of a TB stop gesture. For this reason, when a TT gesture is followed by a TB gesture in the CD order of place of articulation, it takes less time to form the posterior closure resulting in closer gestural coordination and shorter lag durations. On the other hand, when a TB gesture is followed by a TT gesture, more time is needed for the tip of the tongue to form the anterior closure resulting in less gestural coordination and longer lag durations.

6.1.4 Voice assimilation

Regressive voice assimilation across the word boundary is more frequent than progressive in TLA. This is found in both the –V+V and +V-V contexts. These results have been well documented in the literature (Torres 2001; Teifour 1997; Zuraiq & Abu-Joudeh 2013; Burton & Robblee 1997; Kulikov 2011). Progressive voice assimilation only occurs in the –V+V context. Furthermore, voicing spread only occurs in regressive assimilation of voice in the –V+V context. The results also demonstrate that voice assimilation occurs even in heterorganic sequences where no place assimilation occurs. This is not in line with the claims by Zuraiq & Abu-Joudeh (2013) who assert that voice assimilation between C1 and C_2 occurs on the condition that C_1 assimilates in place to C_2. However, in cases where C1 and C2 share the same place of articulation as in /ʃid#tal/ and /dag#kif/, the duration of voicelessness spreading into the HP of voiced C1 increases. This is motivated by the fact that the HP of C1 is not released which results in a juncture geminate therefore facilitating the spread of voicelessness. In cases of voicing spread, the target segment becomes completely voiced indicating that assimilation of voice is categorical (Teifour 1997). Despite this, in line with results from other studies (Burton & Robblee 1997), the spread of voicelessness is always gradient. The target segment is never completely devoiced.

The ratio of voice assimilation spread was not affected by the increase in speech rate. The increase in speech rate did not result in an increase in the ratio of voice assimilation spreading into the target segment. This finding supports the results of the study by Kulikov (2011). However, two exceptions were noted in /ʒit#dis/ and /ʒit#giʃ/ where the ratio of voicelessness spread increased by 55% and 23% respectively.

The investigation concerning the effect of excrescent and epenthetic vowels on voice assimilation spreading also provided interesting results, revealing that epenthetic vowels are not transparent and block the spread of voice assimilation from spreading across the word boundary. For example, in /hatk#gdi:m/ of the CC#CC sequence in which the stops adjacent to the word boundary are of the –V+V context, progressive assimilation of voicelessness was found when SI C1 was partially devoiced in those cases where stop closure overlap was exhibited across the word boundary; consequently, no epenthetic vowels are found. In those cases in which epenthetic vowels did occur, the epenthetic vowel blocked the spread of the voice assimilation process when C1 of the SI cluster retained its voicing.

Excrescent vowels, however, are transparent to and do not block the spread of voice assimilation across the word boundary. This may be caused by the fact that excrescent vowels are not true vowels but the result of the transition from one stop gesture to another whereas epenthetic vowels are true vowels inserted by speakers in order to repair sequences which are not permitted. As a result, excrescent vowels are systematically ignored by phonological processes (Hall 2011). This provides further evidence of the epenthetic vs. excrescent vowel distinction discussed earlier (section 5.3.3).

6.2 Conclusion

The conclusion is divided into three sections. In the first of these, the research questions are reviewed in light of the results which have been obtained. The second section identifies the limitations of the study are considered. Accordingly, directions for future research are proposed afterwards.

6.2.1 Review of research questions in light of results

The central goal of this study is to investigate the way speakers organize speech gestures across word boundaries in TLA. By adopting an Articulatory Phonology framework (Browman & Goldstein 1987, Byrd 1992, Hall 2006, Gafos 2002) and building on the notion of gestures as concrete articulatory movements, this study has addressed how the timing and gestural coordination pattern of stops varies in the C#C, C#CC, CC#C, and CC#CC sequences. The observation of vocal tract activity during the process of speech in terms of gestures helped to facilitate the description of such features as timing, gestural coordination, patterns of epenthesis, and the effect of speech rate. The results of this study have highlighted the importance and adequacy of Articulatory Phonology for describing these speech processes.

This study has highlighted the importance of using multiple methods in the study of speech. In this study, two methods of data analysis were used. The first of these, EPG, allows the monitoring of changes in tongue-palate contact patterns of speech over time at intervals of ten milliseconds. The most important advantage that the EPG has is the ability to monitor articulatory behavior and measure the overlap duration between two adjacent segments. Two native speakers of TLA were recorded using EPG. The other method was acoustic data analysis using PRAAT software. In this method of data analysis, ten native speakers of TLA were recorded two of which were those recorded using the EPG. One of the advantages of this type of analysis is that PRAAT displays speech using a digital spectrogram and time domain waveform. It allows the monitoring of acoustic behavior of speech segments. Since most of the acoustic analysis in this study is based on durations, both these displays are almost equally useful depending on different contexts. In both methods, the recordings were made in normal and fast speech rates in order to investigate the effect of speech rate. Since both methods are known have their advantages and disadvantages, EPG and acoustic results are both equally important in observing and monitoring speech gestures.

Study findings suggest that the effect of the timing of speech segments on each other is not only limited to within SF and SI clusters and word boundaries, but also spreads across word boundaries. In answer to research question 1 whether an increase in the number of stop consonants in a sequence will have an effect on the timing of stops, the results in section 4.2 of the EPG data and section 5.2 of the acoustics data indicate that the effect spreads across the word boundary. Despite the fact that the timing pattern of stops in C#CC, CC#C and CC#CC sequences are underrepresented in literature, the results suggest that the timing of SF and SI stops and clusters was affected by the increase in the number of stops on the adjacent side of the word boundary. The timing of the SF single articulatory gesture stop in tokens of the **C**#C decreases when followed by a SI cluster in tokens of the **C**#CC sequence as a result of an increase in the number of stops in SI position. Similarly, the SI singleton stop in tokens of the C#**C** sequence also exhibits a decrease in its duration when preceded by a SF cluster in tokens of the CC#**C** sequence as a result of the increase in the number of stops in SF position.

Although they exhibit similar timing patterns when occurring as singletons, when occurring as part of a cluster, the effect of the increase in the number of stops in a sequence on the duration of the SF C2 in C**C**#C and SI C1 in C#**C**C sequences differs as a result of the increase in the number of stops when both these stops occur in tokens of the CC#CC sequence. The results indicate that the SF C2 in tokens of the C**C**#C sequence exhibits a decrease in duration as a result of the increase in the number of stops in SI position when occurring in tokens of the C**C**#CC sequence. On the other hand, the SI C1 in tokens of the C#**C**C sequence does not exhibit this decrease as a result of the increase in the number of stops in SF position as in tokens of the CC#**C**C sequence.

This difference in the timing pattern is also found between SF and SI clusters. The results in the EPG data (sections 4.2.3 and 4.2.4) and acoustic data (sections 5.2.3 and 5.2.4) suggest that the timing of SF and SI clusters are affected differently by the increase in the number of stops on the adjacent side of the word boundary. When followed by a SI singleton stop gesture in tokens of the **CC**#C sequence, the duration of SF clusters exhibit a decrease as a result of the increase in the number of stops in SI position in tokens of the **CC**#CC sequence. However, SI clusters in tokens of the C#**CC** sequence are not greatly affected by the increase in the number of stops in SF position in tokens of the CC#**CC** sequence. Furthermore, this variability in the timing of SF clusters in tokens of the **CC**#C and **CC**#CC sequences is a result of the different coordination patterns exhibited between stops in these clusters seen in the EPG data (section 4.3.2.3) and the acoustic data (section 5.3.2.3). In these sections, longer lag durations are found between stops of the SF cluster in tokens of the **CC**#C sequence which increases the duration of the cluster as a whole. However, when the SF cluster occurred in tokens of the **CC**#CC sequence, it exhibited closer gestural coordination resulting in shorter lag durations between stops. On the other hand, SI clusters in tokens of both the C#**CC** and CC#**CC** sequences exhibited a similar gestural coordination pattern exhibiting short lag durations between the stops. These results support previous results showing that SF clusters are more variable in timing than SI clusters (Byrd 2003; Gafos 2002; Marin & Pouplier 2002). This finding is consistent with the C-centre hypothesis (Browman & Goldstein 1988, 2000).

The results also reveal that when a stop is followed by a conflicting tongue gesture, the duration is longer than when it is followed by a non-conflicting tongue gesture. This is found in the SF stop gesture in tokens of the **C**#C and **C**#CC sequences. The duration of a SF coronal stop gesture in tokens of the C#C and C#CC sequences is longer in duration when followed by a conflicting dorsal stop gesture in SI position than when it is followed by a similar coronal stop gesture. The reason for this increase is that the following conflicting gesture requires more time and effort from the speaker and in anticipation of this the HP of the SF stop gesture can be kept in place for a longer period since it is not involved in the production of the following gesture. This result is in line with the findings of other studies which indicate that stops are longer when followed by another stop with a conflicting gesture (Umeda 1977).

The results of the EPG data (section 4.3) and the acoustic data (section 5.3) reveal that gestural coordination and epenthesis patterns vary from one sequence type to another. In answer to research question 2, two patterns of gestural coordination between stops have been found. The first is characterized by short lag duration as a result of closer gestural coordination resulting in an excrescent vowel ranging from 14ms-20ms in normal speech rate. The second is characterized by long lag duration as a result of gestures being pulled apart resulting in an epenthetic vowel which ranges from 43ms-51ms in normal speech rate. The results of both the EPG and acoustics data indicate that the pattern/s of epenthesis are controlled by the phonotactics of TLA which only allows a maximum of two stops to occur in a sequence.

Tokens of the C#C sequence exhibited tight gestural coordination between stops across the word boundary. Since consisting of only two stops in the sequence, the syllabic template of TLA is not violated. Only transitional excrescent vowels were exhibited when stop closure overlap was not observed. When the number of stops exceeds the maximum permitted by the syllabic template in TLA, epenthesis is triggered. In tokens of the C#CC and CC#C sequence where three stops occur in tokens of each sequence, an identical pattern of epenthesis is found. Epenthesis occurs between C1 and C2 in tokens of both sequence types where weak gestural coordination is found. However, closer gestural coordination is exhibited between C2 and C3 stops in tokens of both sequences resulting in short excrescent vowels. In line with results of other studies (Ito 1989), epenthesis is applied to repair illegal sequences that violate the syllabic template (Zsiga 2003; Hall 2011).

In tokens of the four-stop CC#CC sequence, the pattern of epenthesis differed. If the same epenthesis pattern is applied between C1 and C2 of the sequence as in tokens of the C#CC and CC#C sequences, the syllabic template of TLA is not fulfilled. In a four-stop sequence, a pattern of this type produces another three-stop sequence C2C3C4. As a result, the epenthetic vowel is inserted at the word boundary between C2 and C3 of the sequence instead. This causes stops of the SF and SI clusters to exhibit closer gestural coordination since they do not exceed the maximum number of stops permitted in TLA (i.e. two) and excrescent vowels are found to occur in these positions. This epenthesis pattern follows the syllabic template of TLA. These findings confirm the classification of Libyan Arabic as a VC dialect (Kiparsky 2003; Watson 2007).

However, when C1 and C2 of the C#CC sequence are homorganic, epenthesis does not occur categorically (see section 5.3.1.2). This provides evidence that the constraint in the VC and CV language distinction is based on gestures and not segments in this context as discussed in section 6.1.2.

Furthermore, the results also indicate that gestural coordination is weakest at the word boundary in sequences of more than two stops. This observation is well documented in the literature (Hardcastle 1985; Cho 1998, 2001). Stops adjacent to the word boundary are not associated with a single lexical item and belong to two separate words and therefore exhibit weak gestural coordination.

The acoustic results in section 5.3.2.3.1 show that as a result of the presence of an epenthetic vowel between stops of the SF cluster in tokens of the CC#C sequence, a resyllabification process occurs. In tokens of the C**C**#C sequence, SF C2 delinks and bonds with the SI singleton adjacent to the word boundary forming a SI cluster. This was evidenced by the C-centre measurements (section 5.3.2.3.2). As a result of this, the phonological and syntactic boundaries are not aligned in the CC#C sequence. In these cases, the phonological boundary is actually within the SF cluster whereas the syntactic boundary is at the word boundary. Although they are grammatically and lexically different, in phonological terms both the C#CC and CC#C sequences are the same. An identical epenthesis pattern is observed in both sequences.

Results of the acoustic data (section 5.3.3) provide evidence that ICIs occurring between stops in sequences belong to two distinct groups, excrescent and epenthetic vowels. This distinction provides an answer to research question 3. As previously mentioned, the results (section 5.3.3) indicate that distinction between excrescent and epenthetic vowels (Hall 2011) is valid in TLA. This is also in line with other studies (Gafos 2002; Gick & Wilson 2006; Haddad 1984; Davidson & Stone 2004). The distinction is evidenced by both the durations and the effect of the voicing of adjacent segments on the voice values of these vowels. Excrescent vowels are found between stops in tokens of the C#C sequence, the SI cluster in tokens of the C#CC sequence, the SF and SI cluster in tokens of the CC#CC sequence, and finally between C2 and C3 stops in tokens of the CC#C sequence. In all these positions, closer gestural coordination is observed between stop gestures. Epenthetic vowels are found at the word boundary in tokens of the C#CC and CC#CC sequences. They are also found between C1 and C2 stops in tokens of the CC#C sequence.

Epenthetic vowels are inserted by speakers to prevent the occurrence of more than two stops in a sequence and therefore conform to the syllabic template of TLA. However, excrescent vowels occur even when template satisfaction is achieved. Therefore, it can be argued that speakers do not intentionally produce excrescent vowels but that these are simply the result of gestural timing (Davidson & Stone 2004) where the release stage of one gesture is not synchronized with the onset of the following one. The results also indicate that the voice values of both types provide further evidence that they belong to two distinct categories in terms of the effect of the voicing of adjacent segments. Excrescent vowels appear to be more dependent in terms of voicing on the voice value of neighbouring segments. On the other hand, epenthetic vowels are not influenced by the voice values of adjacent segments and are always specified as voiced.

The influence of the order of place of articulation of stops on gestural coordination suggests that stops in the coronal-dorsal order of place of articulation are more closely coordinated than stops in the dorsal-coronal order of place of articulation. This provides an answer to research question 4. The EPG results (section 4.4) and acoustic results (section 5.4) reveal that there is a significant difference between both orders of place of articulation. In line with results of several previous studies (Hardcastle & Roach 1979; Byrd & Tan 1996; Zsiga 2000, 2003; Chitoran et al 2002; Kochetov 2007), tokens of the coronal-dorsal order of place of articulation exhibited closer gestural coordination between stop gestures when a coronal gesture is followed by a dorsal gesture. The EPG and acoustics data reveal shorter lag durations between stop gestures in this order. The results of the EPG data (section 4.4.2) reveal that longer stop closure overlap durations are exhibited in the coronal-dorsal order of place of articulation with a mean overlap duration of 32ms. On the other hand, tokens of the dorsal-coronal order of place of articulation exhibited slightly shorter stop closure overlap durations with a mean of 26ms. Tokens in which a dorsal gesture is followed by a coronal gesture reveal that the gestures are not closely synchronised resulting in a decrease in gestural coordination. These differences have been explained in terms of limitations in the articulatory movement of the tongue as discussed in section 6.1.3.

The results of the voice assimilation investigation (section 5.5) indicate that regressive voice assimilation across the word boundary is more frequent than progressive voice assimilation in TLA. This result is in line with the argument that there is a universal tendency for voice assimilation to be mostly regressive (Torres 2001:15).

The results also indicate that the voicing context of the stops is a crucial factor in determining the direction of voice assimilation spread. Being more common, regressive voice assimilation is found to occur in both the –V+V and +V-V contexts. However, progressive voice assimilation is limited to the –V+V voice context where C1 is the trigger and the target C2 is therefore devoiced. These results provide an answer to research question 5 which was related to whether voice assimilation can occur across the word boundary in TLA.

Furthermore, the results in this study do not confirm the claim that voice assimilation between C1 and C2 occurs on the condition that C1 assimilates in place to C2 (Zuraiq & Abu-Joudeh 2013), since voice assimilation occurs even in heterorganic sequences when no place assimilation occurs. However, in homorganic sequences when a TT gesture is followed by another TT gesture in the +V-V context, the duration of voicelessness spreading into the HP of voiced C1 increases (see section 6.1.4).

The voice value of the trigger segment is also an important factor in determining whether the voice assimilation process is categorical or gradient. The target segment becomes completely voiced as a result of regressive assimilation of voice in the –V+V context. On the other hand, the spread of voicelessness is found to be gradient and incomplete in both the –V+V and +V-V contexts.

Acoustic data results (section 5.5.2) provide further evidence that epenthetic and excrescent vowels belong to two distinct groups in answer to research question 3. The results show that these two types of vowels have different affects on the voice assimilation process. In both regressive and progressive voice assimilation, the voice values of excrescent vowels are always in agreement with the voice value of the trigger segment. If the voice value of C1 is voiced, in progressive voice assimilation the excrescent vowel occurring between C1 and C2 is always voiced. In the same process, if the voice value of C1 is voiceless, the voice value of the excrescent vowel is voiceless. A similar pattern is also found in regressive voice assimilation. This indicates that excrescent vowels are transparent to and do not block the spread of the voice assimilation process.

The results of the effect of epenthetic vowels on voice assimilation are different. Being more independent in their voice value, epenthetic vowels do not appear to transparent and block the process of voice assimilation.

Finally, results reveal that the speech rate has an effect on segment durations and gestural coordination between stops. In order to address research question 6, the data was recorded at normal and fast speech rates. The results of the timing of stops, sections 4.2 and 5.2, show that the increase in speech rate resulted in a decrease in the duration of stops. At fast speech rate, the increase in the velocity of the articulators resulted in a decrease in their durations. This is well documented in the literature (Gay 1981). However, the timing pattern exhibited by the stops at normal speech rate did not remain consistent at fast speech rate. The rate of decrease in duration of stops as a result of the increase in the number of stops in the sequence was not consistent at fast speech rate. In terms of gestural coordination between stops in the four sequence types, the increase in speech rate resulted in closer gestural coordination between stops which is well documented in the literature (Huinck et. al 2004; Byrd & Tan 1996; Hall 2006). Despite this, the results show that the increase in speech rate only affects positions where epenthetic vowels occur. Lag durations decreased in positions where epenthetic vowels occurred, indicating that gestures are more closely coordinated at fast speech rate. However, an increase in speech rate did not affect the positions where excrescent vowels occurred and no significant decrease in the duration of excrescent vowels was observed. Furthermore, previous studies have documented that excrescent vowels disappear at fast speech rates (Gafos 2002; Hall 2006). Despite this, the results (sections 4.3.1 and 5.3.1) show that the percentages of unmasked stop releases were not greatly affected as a result of the increase in speech rate.

The results of the EPG data (section 4.4.2) also indicate that stop closure overlap duration was not affected by the increase in speech rate. However, a slight increase in the mean stop closure overlap duration was exhibited between stops for the CD order of place of articulation.

6.2.2 Limitations of the study

This study attempts to describe the production of lingual-palatal stops across the word boundary in TLA. However, some limitations mostly for reasons such as space limitations, time, and cost of EPG plates are hereby mentioned. Although the aim of this study is to investigate stop consonant production across the word boundary in TLA, the study was limited to lingual-palatal non-emphatic stops. Bilabial and emphatic stops were excluded from the study especially because the EPG does not account for bilabial movement or for secondary articulations of open approximation.

The study could also have considered other factors that might affect gestural coordination. These include stress and gender. The influence of gender was excluded since no female speakers of TLA could be located at the University of Leeds during the time allocated for the study.

6.2.3 Directions for future research

This study has contributed to the phonetics of Libyan Arabic and provided a better understanding of speech production and the temporal organisation of articulatory gestures. This work has also demonstrated that adopting an Articulatory Phonology approach and a methodology which combines EPG and acoustics can be effective in analyzing speech production. Future application of this theoretical framework and technique to the study of speech production will be very useful. Below are a few possible directions for future work.

The quality of the epenthetic vowel applied in TLA merits further investigation. Several studies have indicated that the vowel used in epenthesis is usually a schwa [ə]. However, others argue that it is language specific and involves the default vowel of a language. This can be identified by investigating F1 and F2 of the epenthetic vowels and comparing them with formant frequencies of other vowels in TLA.

Expanding the consonant inventory for investigation such as fricatives and bilabials, and emphatics should be considered. Coronal and dorsal closures do not constrain bilabial articulations because the tongue and lips are much more independent of each other than the tongue tip and tongue dorsum. A study of this type would shed light on whether the same gestural coordination pattern exhibited by coronal and dorsal stops is also found in all consonant sequences.

Furthermore, financial resources permitting, the use of other instruments be considered in future studies. These include Electromagnetic Articulography (EMA) and Magnetic Resonance Imaging (MRI), both of which have been successfully used in several studies investigating speech processes.

Appendices

Appendix A: Acoustic results of ICI durations for individual speakers at fast speech rate

Fast						
Token	**Mean # ICI (ms)**	**N**	**Std Dev**	**Mean SI ICI (ms)**	**N**	**Std Dev**
Speaker 1	33	35	13	13	45	7
Speaker 2	30	30	11	17	48	6
Speaker 3	33	31	8	11	48	4
Speaker 4	25	33	8	12	48	4
Speaker 5	47	44	11	14	48	6
Speaker 6	43	48	7	18	48	6
Speaker 7	44	36	19	20	47	7
Speaker 8	36	45	11	13	48	4
Speaker 9	30	42	9	10	46	6
Speaker 10	42	45	8	21	48	5

Mean #ICI and SI ICI in C#CC sequence across all tokens at fast speech rate

Fast						
Token	**Mean SF ICI (ms)**	**N**	**Std Dev**	**Mean # ICI (ms)**	**N**	**Std Dev**
Speaker 1	28	4	6	10	23	6
Speaker 2	34	4	6	16	21	8
Speaker 3	31	4	8	11	22	5
Speaker 4	23	4	6	13	24	6
Speaker 5	38	4	5	14	24	6
Speaker 6	26	4	4	17	24	7
Speaker 7	29	4	8	25	24	5
Speaker 8	30	4	8	13	24	4
Speaker 9	27	4	6	10	24	5
Speaker 10	32	4	4	16	24	7

Mean SF ICI and # ICI in CC#C sequence across all tokens at fast speech rate

Fast									
Token	**Mean SF ICI (ms)**	**N**	**Std Dev**	**Mean # ICI (ms)**	**N**	**Std Dev**	**Mean SI ICI (ms)**	**N**	**Std. Dev**
Speaker1	21	4	10	40	39	11	11	45	5
Speaker2	14	4	4	50	48	12	10	48	5
Speaker3	31	4	8	24	24	12	10	48	4
Speaker4	12	4	4	46	48	8	10	48	5
Speaker5	16	4	5	49	48	12	12	48	6
Speaker6	20	4	4	53	48	11	15	48	5
Speaker7	22	4	7	59	48	15	19	48	5
Speaker8	11	4	4	49	48	12	12	44	4
Speaker9	11	4	4	34	37	14	11	48	6
Speaker10	17	4	3	45	48	10	19	48	6

Mean SF ICI, # ICI, and SI ICI in CC#CC sequence across all tokens at fast speech rate

Appendix B: Mean C-centre durations

C_centre	Token	Mean	N	Std. Deviation
C#CV	ʒit#tal	170.70	30	20.403
	ʒit#dis	171.27	30	23.609
	ʒit#kalb	160.80	30	19.642
	ʒit#giʃ	176.67	30	25.936
	ʃid#tal	178.42	30	21.652
	ʃid#dis	171.60	30	26.930
	ʃid#kif	168.87	30	16.882
	ʃid#giʃ	179.83	30	21.262
	fak#tal	183.13	30	13.929
	fak#dam	189.58	30	20.394
	fak#kif	169.60	30	18.660
	fak#giʃ	183.77	30	20.564
	dag#tal	184.38	30	15.943
	dag#dam	183.00	30	18.212
	dag#kif	169.03	30	21.960
	dag#giʃ	180.57	30	22.833
	Total	176.33	480	21.816
#CCV	bat#tkasir	123.12	30	11.104
	nat#dkar	161.65	30	18.207
	nat#kdab	142.57	30	14.229
	nat#gtal	143.17	30	9.047
	ʃad#tkasir	129.25	30	18.894
	ʃad#dkar	157.18	30	20.390
	ʃad#ktir	153.60	30	14.829
	ʃad#gtal	138.88	30	10.350
	fak#tkasir	122.38	30	8.885

	fak#dkar	155.40	30	17.906
	fak#ktir	152.00	30	18.111
	fak#gtal	182.07	30	35.219
	hag#tkasir	121.13	30	8.353
	hag#dkar	150.88	30	14.523
	nag#ktir	156.43	30	15.770
	hag#gdi:m	185.30	30	42.482
	Total	148.44	480	26.746
CC#CV	wagt#tal	139.55	30	12.895
	wagt#daf	142.10	30	15.716
	wagt#kif	130.97	30	13.732
	wagt#giʃ	145.52	30	13.406
	ʕagd#tal	146.30	30	13.988
	ʕagd#dam	144.67	30	11.675
	ʕagd#kam	143.45	30	16.695
	ʕagd#gas	154.18	30	18.912
	hatk#tal	150.42	30	15.600
	hatk#dam	154.30	30	17.677
	hatk#kif	138.00	30	11.882
	hatk#giʃ	149.43	30	15.717
	fatg#tal	153.18	30	12.485
	fatg#dam	151.20	30	16.408
	fatg#kam	149.93	30	20.267
	fatg#gal	163.33	30	19.404
	Total	147.28	480	17.096

Mean C-centre to anchor point durations in C#CCV sequence compared to CC#CV and C#CV sequences in normal speech rate across all tokens

C_centre	Token	Mean	N	Std. Deviation
C#CV	ʒit#tal	117.2	30	8.493
	ʒit#dis	109.7	30	10.376
	ʒit#kalb	132.5	30	10.608
	ʒit#giʃ	156.1	30	23.675
	ʃid#tal	169.2	30	23.636
	ʃid#dis	145.2	30	14.070
	ʃid#kif	142.3	30	15.790
	ʃid#giʃ	148.6	30	15.549
	fak#tal	140.3	30	7.521
	fak#dam	135.3	30	8.810
	fak#kif	139.1	30	14.391
	fak#giʃ	144.2	30	13.866
	dag#tal	153.0	30	8.969
	dag#dam	156.0	30	9.129
	dag#kif	149.6	30	17.758
	dag#giʃ	146.3	30	18.773
	Total	142.8	48	20.229
#CCV	bat#tkasi	100.0	30	16.426
	nat#dkar	113.4	30	21.125
	nat#kdab	122.6	30	20.097
	nat#gtal	134.7	30	17.346
	ʃad#tkasi	135.0	30	15.768
	ʃad#dkar	140.2	30	11.890
	ʃad#ktir	134.2	30	19.456
	ʃad#gtal	136.9	30	15.790
	fak#tkasi	107.1	30	7.535

	fak#dkar	121.5	30	17.055
	fak#ktir	122.4	30	16.596
	fak#gtal	128.0	30	14.648
	hag#tkas	138.4	30	24.877
	hag#dkar	142.8	30	29.274
	nag#ktir	133.9	30	28.433
	hag#gdi:	137.8	30	28.563
	Total	128.0	48	23.096
CC#CV	wagt#tal	104.1	30	7.805
	wagt#daf	111.9	30	13.916
	wagt#kif	124.8	30	9.062
	wagt#giʃ	129.9	30	12.474
	ʕagd#tal	142.3	30	13.935
	ʕagd#da	131.8	30	13.997
	ʕagd#ka	135.7	30	11.486
	ʕagd#gas	138.5	30	11.942
	hatk#tal	109.5	30	8.768
	hatk#da	122.2	30	11.657
	hatk#kif	132.8	30	9.842
	hatk#giʃ	133.6	30	9.676
	fatg#tal	128.0	30	8.538
	fatg#dam	134.9	30	9.614
	fatg#kam	128.8	30	16.237
	fatg#gal	128.4	30	10.368
	Total	127.3	48	15.288

Mean C-centre to anchor point durations in C#CCV sequence compared to CC#CV and C#CV sequences in fast speech rate across all tokens

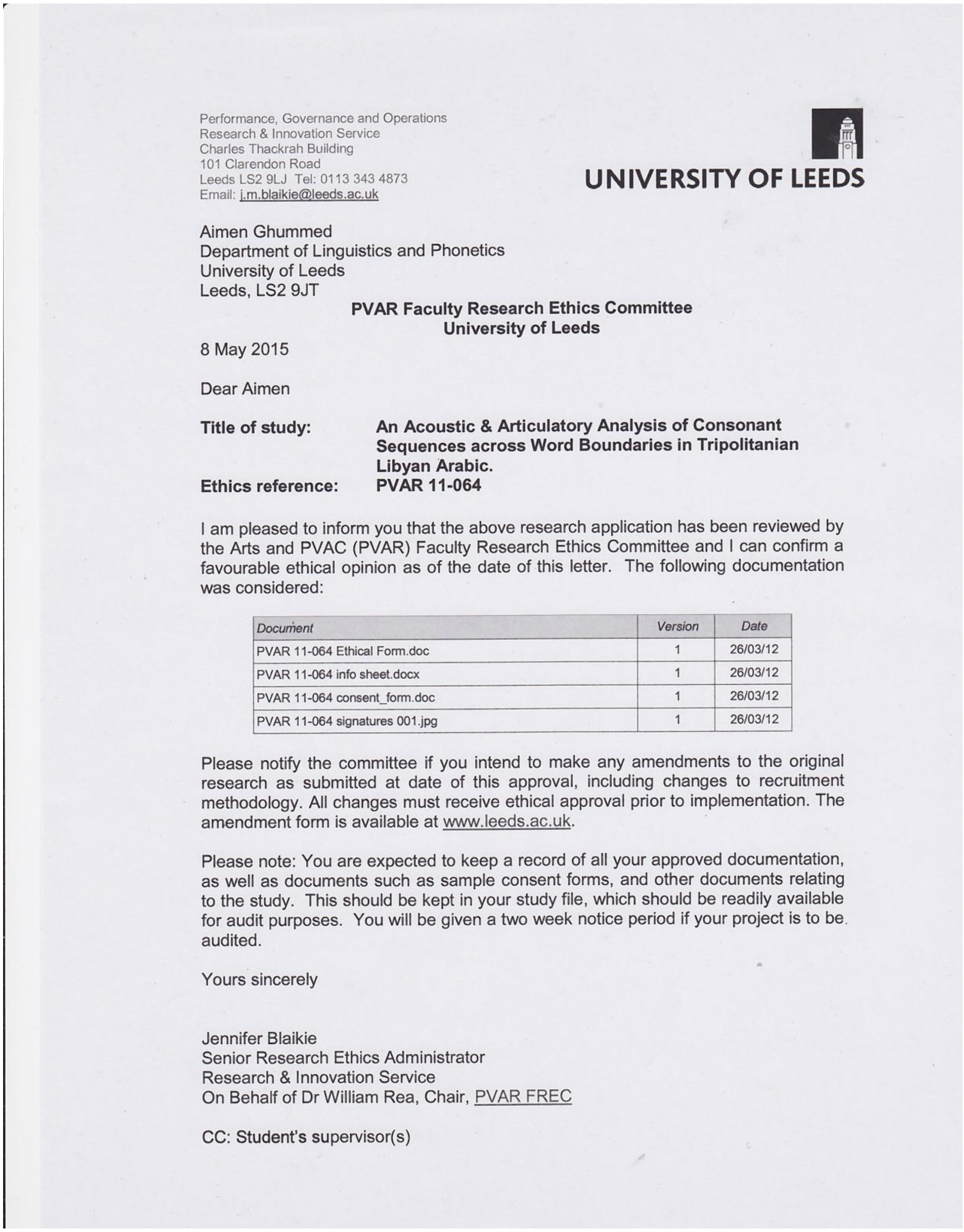
Speaker		Mean (ms)	N	Std. Deviation
Speaker 1	**C#CV**	143.86	48	14.385
	#CCV	125.65	48	11.665
	CC#CV	119.46	48	9.660
Speaker 2	**C#CV**	162.91	48	15.823
	#CCV	140.28	48	19.665
	CC#CV	143.08	48	15.210
Speaker 3	**C#CV**	183.76	48	16.068
	#CCV	148.00	48	24.578
	CC#CV	154.45	48	18.736
Speaker 4	**C#CV**	178.29	48	14.352
	#CCV	154.30	48	16.977
	CC#CV	150.05	48	12.419
Speaker 5	**C#CV**	167.49	48	14.542
	#CCV	146.42	48	17.599
	CC#CV	150.91	48	10.784
Speaker 6	**C#CV**	176.77	48	12.246
	#CCV	142.36	48	19.864
	CC#CV	143.22	48	10.290
Speaker 7	**C#CV**	170.15	48	16.668
	#CCV	147.02	48	22.647
	CC#CV	143.93	48	10.463
Speaker 8	**C#CV**	204.24	48	15.834
	#CCV	165.26	48	31.170
	CC#CV	160.69	48	11.827
Speaker 9	**C#CV**	195.50	48	15.076
	#CCV	156.86	48	31.576
	CC#CV	148.34	48	12.863
Speaker 10	**C#CV**	180.29	48	13.598
	#CCV	158.23	48	39.403
	CC#CV	158.71	48	16.829

Mean C-centre to anchor point durations in C#CCV sequence compared to CC#CV and C#CV sequences in normal speech rate for each speaker

Speaker		Mean (ms)	N	Std. Deviation
Speaker 1	**C#CV**	112.69	48	10.999
	#CCV	104.17	48	20.555
	CC#CV	106.64	48	11.018
Speaker 2	**C#CV**	127.83	48	12.115
	#CCV	122.38	48	19.340
	CC#CV	122.78	48	12.247
Speaker 3	**C#CV**	168.91	48	21.463
	#CCV	135.89	48	16.238
	CC#CV	137.26	48	15.469
Speaker 4	**C#CV**	148.05	48	14.501
	#CCV	138.47	48	15.114
	CC#CV	134.83	48	13.506
Speaker 5	**C#CV**	142.53	48	15.776
	#CCV	133.78	48	16.643
	CC#CV	135.03	48	11.248
Speaker 6	**C#CV**	138.63	48	7.716
	#CCV	112.18	48	14.451
	CC#CV	113.27	48	10.605
Speaker 7	**C#CV**	136.28	48	13.586
	#CCV	123.77	48	16.536
	CC#CV	132.09	48	11.360
Speaker 8	**C#CV**	151.80	48	9.637
	#CCV	132.88	48	21.944
	CC#CV	129.90	48	9.218
Speaker 9	**C#CV**	156.44	48	11.665
	#CCV	143.77	48	29.729
	CC#CV	135.58	48	10.633
Speaker 10	**C#CV**	143.68	48	17.012
	#CCV	131.15	48	25.207
	CC#CV	125.06	48	11.703

Mean C-centre to anchor point durations in C#CCV sequence compared to CC#CV and C#CV sequences in fast speech rate for each speaker

Appendix C: Ethical approval, consent form, and information sheet



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Aimen Ghummed
Department of Linguistics and Phonetics
University of Leeds
Leeds, LS2 9JT

PVAR Faculty Research Ethics Committee
University of Leeds

8 May 2015

Dear Aimen

Title of study: **An Acoustic & Articulatory Analysis of Consonant Sequences across Word Boundaries in Tripolitanian Libyan Arabic.**

Ethics reference: **PVAR 11-064**

I am pleased to inform you that the above research application has been reviewed by the Arts and PVAC (PVAR) Faculty Research Ethics Committee and I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	*Version*	*Date*
PVAR 11-064 Ethical Form.doc	1	26/03/12
PVAR 11-064 info sheet.docx	1	26/03/12
PVAR 11-064 consent_form.doc	1	26/03/12
PVAR 11-064 signatures 001.jpg	1	26/03/12

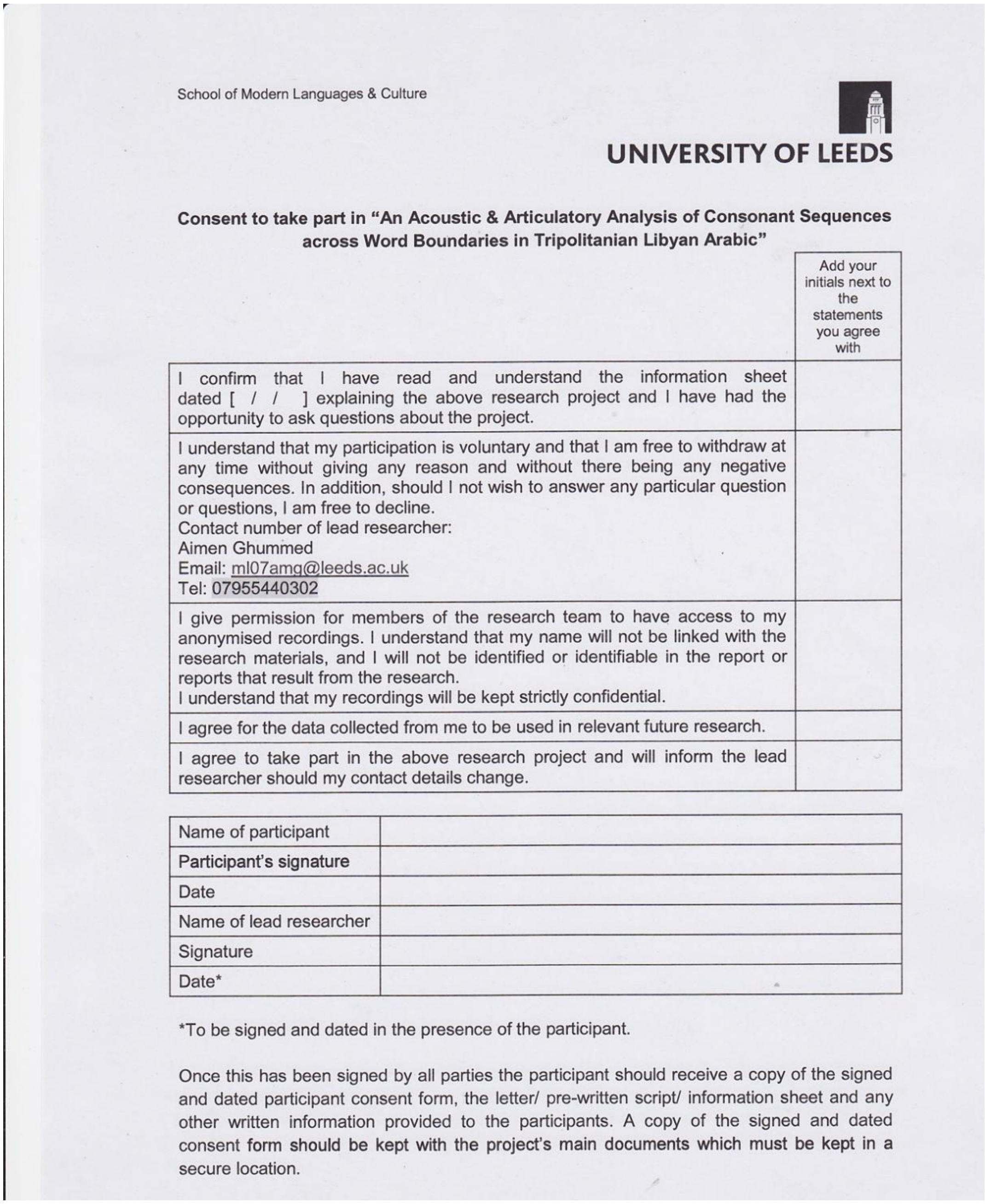
Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at www.leeds.ac.uk.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator
Research & Innovation Service
On Behalf of Dr William Rea, Chair, PVAR FREC

CC: Student's supervisor(s)



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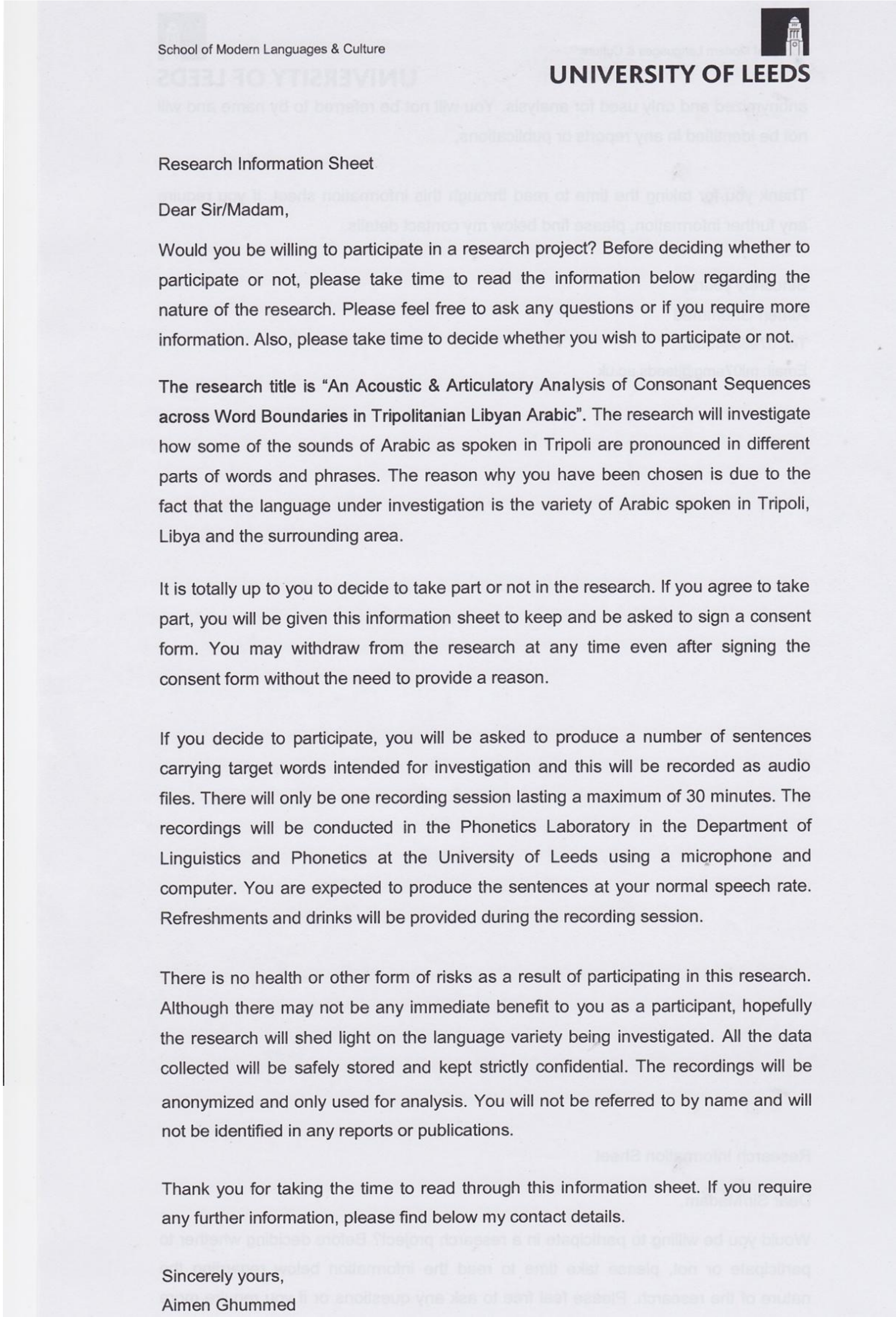
Consent to take part in "An Acoustic & Articulatory Analysis of Consonant Sequences across Word Boundaries in Tripolitanian Libyan Arabic"

	Add your initials next to the statements you agree with
I confirm that I have read and understand the information sheet dated [/ /] explaining the above research project and I have had the opportunity to ask questions about the project.	
I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. Contact number of lead researcher: Aimen Ghummed Email: ml07amg@leeds.ac.uk Tel: 07955440302	
I give permission for members of the research team to have access to my anonymised recordings. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. I understand that my recordings will be kept strictly confidential.	
I agree for the data collected from me to be used in relevant future research.	
I agree to take part in the above research project and will inform the lead researcher should my contact details change.	

Name of participant	
Participant's signature	
Date	
Name of lead researcher	
Signature	
Date*	

*To be signed and dated in the presence of the participant.

Once this has been signed by all parties the participant should receive a copy of the signed and dated participant consent form, the letter/ pre-written script/ information sheet and any other written information provided to the participants. A copy of the signed and dated consent form should be kept with the project's main documents which must be kept in a secure location.



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Research Information Sheet

Dear Sir/Madam,

Would you be willing to participate in a research project? Before deciding whether to participate or not, please take time to read the information below regarding the nature of the research. Please feel free to ask any questions or if you require more information. Also, please take time to decide whether you wish to participate or not.

The research title is "An Acoustic & Articulatory Analysis of Consonant Sequences across Word Boundaries in Tripolitanian Libyan Arabic". The research will investigate how some of the sounds of Arabic as spoken in Tripoli are pronounced in different parts of words and phrases. The reason why you have been chosen is due to the fact that the language under investigation is the variety of Arabic spoken in Tripoli, Libya and the surrounding area.

It is totally up to you to decide to take part or not in the research. If you agree to take part, you will be given this information sheet to keep and be asked to sign a consent form. You may withdraw from the research at any time even after signing the consent form without the need to provide a reason.

If you decide to participate, you will be asked to produce a number of sentences carrying target words intended for investigation and this will be recorded as audio files. There will only be one recording session lasting a maximum of 30 minutes. The recordings will be conducted in the Phonetics Laboratory in the Department of Linguistics and Phonetics at the University of Leeds using a microphone and computer. You are expected to produce the sentences at your normal speech rate. Refreshments and drinks will be provided during the recording session.

There is no health or other form of risks as a result of participating in this research. Although there may not be any immediate benefit to you as a participant, hopefully the research will shed light on the language variety being investigated. All the data collected will be safely stored and kept strictly confidential. The recordings will be anonymized and only used for analysis. You will not be referred to by name and will not be identified in any reports or publications.

Thank you for taking the time to read through this information sheet. If you require any further information, please find below my contact details.

Sincerely yours,
Aimen Ghummed

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